NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

T7621

**NATURAL CONVECTION COOLING OF A 3 BY 3
ARRAY OF RECTANGULAR PROTRUSIONS IN AN
ENCLOSURE FILLED WITH DIELECTRIC LIQUID:
EFFECTS OF BOUNDARY CONDITIONS
AND COMPONENT ORIENTATION**

by

Edgardo I. Torres

December 1988

Thesis Advisor: Yogendra Joshi

T242393

REPORT DOCUMENTATION PAGE

1a Report Security Classification Unclassified		1b Restrictive Markings		
2a Security Classification Authority		3 Distribution Availability of Report		
2b Declassification/Downgrading Schedule		Approved for public release; distribution is unlimited.		
4 Performing Organization Report Number(s)		5 Monitoring Organization Report Number(s)		
6a Name of Performing Organization Naval Postgraduate School	6b Office Symbol *(If Applicable)*	7a Name of Monitoring Organization Naval Postgraduate School		
6c Address *(city, state, and ZIP code)* Monterey, CA 93943-5000		7b Address *(city, state, and ZIP code)* Monterey, CA 93943-5000		
8a Name of Funding/Sponsoring Organization	8b Office Symbol *(If Applicable)*	9 Procurement Instrument Identification Number		
8c Address *(city, state, and ZIP code)*		10 Source of Funding Numbers		
		Program Element Number	Project No	Task No	Work Unit Accession No

11 Title *(Include Security Classification)* Natural Convection Cooling of a 3 by 3 Array of Rectangular Protrusions in an Enclosure Filled with Dielectric Liquid: Effects of Boundary Conditions and Component Orientation

12 Personal Author(s) Edgardo I. Torres

13a Type of Report Master's Thesis	13b Time Covered From To	14 Date of Report *(year, month,day)* December 1988	15 Page Count 139

16 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 Cosati Codes			18 Subject Terms *(continue on reverse if necessary and identify by block number)*
Field	Group	Subgroup	Direct Immersion, Natural Convection Cooling, Dielectric Liquid Protrusions, Enclosure, Simulated Circuit Board, Strip Heaters, Flow Visualization, Convective Heat Transfer

19 Abstract *(continue on reverse if necessary and identify by block number)*

An experimental investigation of natural convection immersion cooling of two configurations of discrete heat sources in an enclosure filled with Fluorinert FC-75 has been conducted. A three by three array of rectangular protrusions was employed.

In the first study, using the same equipment set-up of Benedict [Ref. 13], the influence of changing the enclosure bottom surface boundary condition on flow patterns and heat transfer characteristics was examined. Both insulated and uniform temperature boundary conditions were considered.

In the second set of experiments, a new chamber with the protrusions oriented vertically was assembled and effects of component orientation on the heat transfer characteristics were examined. In addition, timewise variations of temperature in several locations were measured and interpreted at different power levels.

20 Distribution/Availability of Abstract	21 Abstract Security Classification	
[X] unclassified/unlimited ☐ same as report ☐ DTIC users	Unclassified	
22a Name of Responsible Individual Professor Yogendra Joshi	22b Telephone *(Include Area code)* (408) 646-3400	22c Office Symbol 69Ji

DD FORM 1473, 84 MAR   83 APR edition may be used until exhausted   security classification of this page

All other editions are obsolete   Unclassified

i

**Natural Convection Cooling of a 3 by 3 Array of Rectangular
Protrusions in an Enclosure Filled with Dielectric Liquid: Effects
of Boundary Conditions and Component Orientation**

by

Edgardo I. Torres
LT, Columbian Navy
B.S., Columbian Naval Academy, 1986

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
December 1988

ABSTRACT

An experimental investigation of natural convection immersion cooling of two configurations of discrete heat sources in an enclosure filled with Fluorinert FC-75 has been conducted. A three by three array of rectangular protrusions was employed.

In the first study, using the same equipment set-up of Benedict [Ref. 13], the influence of changing the enclosure bottom surface boundary condition on flow patterns and heat transfer characteristics was examined. Both insulated and uniform temperature boundary conditions were considered.

In the second set of experiments, a new chamber with the protrusions oriented vertically was assembled and effects of component orientation on the heat transfer characteristics were examined. In addition, timewise variations of temperature in several locations were measured and interpreted at different power levels.

Thesis
T7621
C.1

TABLE OF CONTENTS

LIST OF FIGURES

TABLE OF SYMBOLS AND ABBREVIATIONS

Symbol	Description	Units
A	Area	m^2
α	Thermal diffusivity	m^2/sec
β	Volumetric expansion coefficient	$1/K$
c_p	Specific heat	$J/kg\text{-}°C$
emf	Thermocouple voltage	volt
g	Acceleration of gravity	m/sec^2
Gr	Grashof number	Dimensionless
h	Heat transfer coefficient	$W/m^2\text{-}°C$
k	Thermal conductivity	$W/m\text{-}°C$
L	Characteristic length	m
L1	Component length in the vertical direction	m
L2	Summation of the ratios of the component fluid exposed areas to their perimeters	m
Nu	Nusselt number	Dimensionless
Nu1	Nusselt number with length scale L1	Dimensionless
Nu2	Nusselt number with length scale L2	Dimensionless
ν	Kinematic viscosity	m^2/sec
ω	Uncertainty in the variables	Various

viii

Power	Power dissipated by the heaters	W
Pr	Prandtl number	Dimensionless
Q_{conv}	Energy added to the fluid	W
Q_{in}	Energy input to the heaters	W
Q_{loss}	Energy loss by conduction	W
Q_{net}	Net power dissipated by the heater	W
R_c	Total thermal resistance	°C/W
R_p	Resistance of the precision resistor	ohms
Ra_f	Flux-based Rayleigh number	Dimensionless
Ra_t	Temperature-based Rayleigh number	Dimensionless
D	Density	kg/m^3
T_{avg}	Average of component temperature	°C
T_b	Back surface temperature of board	°C
T_c	Average heat exchanger temperature	°C
T_f	Average film temperature	°C
T_s	Back surface temperature of the component	°C
T_{sink}	Average temperature of the heat exchangers	°C
V_h	Voltage Across the Heaters	Volts
V_{in}	Input voltage	Volts
w	Chamber width	m
W	Unit of power	W

I. INTRODUCTION

A. STATEMENT OF THE PROBLEM

With the increase in circuit packaging density associated with the miniaturization of microelectronic components, heat dissipation has become a major problem in the design and construction of digital computers and high-power electronic equipment in general. Several alternatives to the solution of the problem have been studied in the past 10 years, including that of Chu [Ref. 1]. Among these, immersion cooling appears to be one of the most effective for achieving high heat-transfer coefficients.

B. IMMERSION COOLING: ANALYTICAL AND EXPERIMENTAL STUDIES

From the construction of the first electronic digital computer, the solution to the problem of heat dissipation from high packaging density electronic equipment has not been easy. Even though very interesting forced convection methods have been studied and very frequently used (Chu [Ref. 1] describes several methods of air- and water-forced convection cooling), the hardware that has to be added to supply the additional power and to store and circulate the cooling liquid can be cumbersome in any application.

The direct immersion of the electronic circuitry into dielectric liquids improves its cooling capability significantly. Baker [Ref. 2] found liquid cooling by free convection to be more than three times as

effective as free convective air cooling of the same device. He made heat transfer measurements from thin-film tantalum nitride resistors evaporated on Corning 7059 glass substrates. The substrates were 1.0 by 2.6 by 0.12 cm. All resistors were rectangular, with their height (dimension parallel to the flow) one-half their base. The surface areas of the resistors were 0.0106, 0.104, 0.477, and 2.00 cm^2. Two liquids were used in the study: freon with a Prandtl number of 3.9, and Dow Corning #200 silicone dielectric liquid with a Prandtl number of 126. The results showed that the heat transfer coefficient is approximately proportional to the cube root of the reciprocal of viscosity. It was also found that the convection coefficient does increase significantly as the source size decreases. The free convection heat transfer coefficient for the smallest source was more than an order of magnitude greater than for the largest source operated under the same conditions.

In a following study, Baker [Ref. 3] also examined different cooling techniques, such as nucleate boiling, forced convection, and bubble-induced mixing for cooling small heat sources.

Park and Bergles [Ref. 4] conducted experimental studies of natural convection from discrete flush-mounted rectangular heat sources on a circuit board substrate. Micro-electronic circuit elements were simulated with thin foil heaters supplied with DC power. Measurements were also made for protruding heaters of varying widths, in water and R-113. They found and documented the increase in heat transfer coefficient with decreasing width. This effect was greater in R-113 than in water. Also, for protruding heaters, the heat transfer

2

coefficients for the upper heaters in an array were found to be higher than those for the lower heaters. This behavior was not observed for flush-mounted heaters. As the distance between heaters increased, so did the heat transfer coefficients.

Chen, et al. [Ref. 5] made an experimental study of natural convection heat transfer in a liquid-filled rectangular enclosure with 10 protruding heaters from one vertical wall. The top surface of the enclosure maintained at a uniform temperature acted as the heat sink. All other surfaces, except the heater locations, were unheated. The enclosure was 16.7 cm in height, 2.3 cm in width, and 19.6 cm in depth (horizontal z-direction of the heaters). The 10 heaters were 0.8 cm high, 1.11 cm wide, and 19.6 cm deep. The vertical spacing between heaters was equal to the heater height. Distilled water and ethylene glycol were used as working fluids. Experimental results show that the bottom heater (heater 1), except for high Rayleigh number runs, has the highest heat transfer coefficient. The heat transfer coefficients at heaters 7, 8, and 9 are nearly the same and present the lowest values among the heaters. It was also shown that heat transfer coefficient decreases up to heater 7. At high Rayleigh numbers, the top heater (10) has the highest heat transfer coefficients. The flow visualization carried out indicates a core flow within the enclosure and a recirculating cell in the gap between heaters. Approximate measurements of the fluid velocity were provided from the particle traces in the flow visualization.

Keyhani, et al. [Ref. 6] experimentally studied the buoyancy-driven flow and heat transfer in a vertical cavity with discrete flush heat sources on one vertical wall while the other vertical wall was cooled at a constant temperature. This enclosure contained 11 alternatively unheated and flush-mounted rows of isoflux heated strips. The liquid was ethylene-glycol with a Prandtl number of 150.

To examine the flow structure, visualization experiments were conducted for several power inputs. Finely ground aluminum powder (5 to 20 microns in size) was used to visualize the flow. The observed flow for a power input of 10 watts was highly structured except for small regions near the end walls. A primary flow circulating from the hot wall to the cold wall, a secondary flow with the same sense of circulation as the primary flow, and a tertiary flow in the opposite direction of the secondary flow were observed in the photographs taken at this power level. At a higher power level of 40 watts, the flow pattern above the mid-height region of the cavity showed transition from laminar to turbulent flow along the surface with heaters. The downward flow along the cold wall was still laminar. For a fixed power input, the heat transfer coefficient generally decreased with increase in height (or heater number). The rate at which Nusselt number decreased with the increase in heater number was found to be a strong function of the heater location.

Kelleher, et al. [Ref. 7] and Lee, et al. [Ref. 8] studied experimentally and numerically the cooling by natural convection of a water-filled rectangular enclosure with a long heater protruding from one vertical

4

wall and conducted flow visualization and heat transfer measurements with the heater at three different elevations. They found the two-dimensional flow to be dual-celled, consisting of a buoyancy-driven upper cell, in which the major part of the fluid motion takes place and which accounts for the majority of the convective heat transfer, and a shear-driven lower cell in which the fluid motion arises due to the viscous drag from the upper cell.

Liu, et al. [Ref. 9] used a three-dimensional finite difference method to study the natural convection cooling of an array of chips mounted on a vertical wall of a three-dimensional rectangular enclosure filled with a dielectric fluid Fluorinert FC 75. They found the long time solution to be oscillatory. Maximum chip temperatures were found on the top surfaces of the three top chips. However, these maximum temperatures did not all occur at the same time, but alternated among these three chips as time proceeded in a rather regular fashion. It was also observed that the bottom sink was quite ineffective in removing heat from the enclosure and that the convective circulation was essentially limited to the chip areas.

Joshi, et al. [Ref. 10] carried out an experimental investigation to study the natural convection cooling of a 3 by 3 array of heated protrusions in a rectangular enclosure filled with dielectric fluid FC-75. They observed that at low power levels (0.1 watts), the flow structure was largely determined by the thermal conditions at the enclosure surfaces. With increasing power levels (0.7 to 3.0 watts), an upward flow developed adjacent to each column of components. The flow away

from the elements became strongly three-dimensional and time-dependent with increasing thermal inputs. Component surface temperatures were used to obtain a heat transfer correlation over the range of power levels examined.

Liu, et al. [Ref. 11] carried out a three-dimensional numerical study of immersion cooling of a chip array by laminar natural convection in a rectangular enclosure filled with a dielectric liquid. They determined the local temperature responses on the chip surfaces, their dynamic behaviors, and their dependence on the enclosure gap size. It was found that the temperature responses are decidedly oscillatory with wave forms ranging from simple to complex, and that maximum chip surface temperatures occur on the top row of chips for large gap sizes but oscillate among all three rows of chips for small gap sizes.

C. OBJECTIVES

The work reported here is a continuation of thesis research conducted at the Naval Postgraduate School by Pamuk [Ref. 12] and Benedict [Ref. 13]. The numerical studies by Liu, et al. [Ref. 9] and Liu, et al. [Ref. 11] were the motivation for some of the specific investigations carried out.

The objectives of the present investigation are twofold: The first is to examine the effect of bottom surface boundary condition on thermal transport in the natural convection cooling of a 3 by 3 array of horizontally arranged protruding elements on a vertical wall. The second objective is to examine heat transfer, fluid flow characteristics,

6

and the influence of the width of the chamber during the natural convection cooling of a 3 by 3 array of vertically arranged protruding elements on a vertical wall. Temperature fluctuation measurements were plotted and compared with existing numerical analysis of Liu, et al. [Refs. 9 and 11] and Benedict [Ref. 13]. For both studies, flow visualizations were also carried out.

II. EXPERIMENTAL SET-UP

A. GENERAL CONSIDERATIONS

Two different experimental configurations were used for the studies reported here. In the first, a 3 by 3 array of rectangular elements with the largest dimension aligned horizontally was examined. In the second study, the largest dimensions were in the vertical direction. The two experimental configurations are next described.

The details of the experimental procedures are available in Benedict [Ref. 13]. The Data Acquisition Programs were the same as used by Pamuk [Ref. 12] and Benedict [Ref. 13] with minor modifications in output format and number of channels. These programs are collected in Appendix D.

1. Experimental Set-Up for the Horizontal Arrangement

A schematic sketch of the arrangement is provided in Figure 2.1 (after Benedict [Ref. 13]). The configuration is the same as the one used by Joshi, et al. [Ref. 9] and Benedict [Ref. 13]. The distribution of the components and the top view of the chamber are illustrated in Figures 2.2 and 2.3 (both after Benedict [Ref. 13]).

This part of the thesis examines the effect of changing the enclosure bottom surface boundary condition on the overall thermal behavior of the system. A more detailed description of the experimental arrangement can be found in Benedict [Ref. 13].
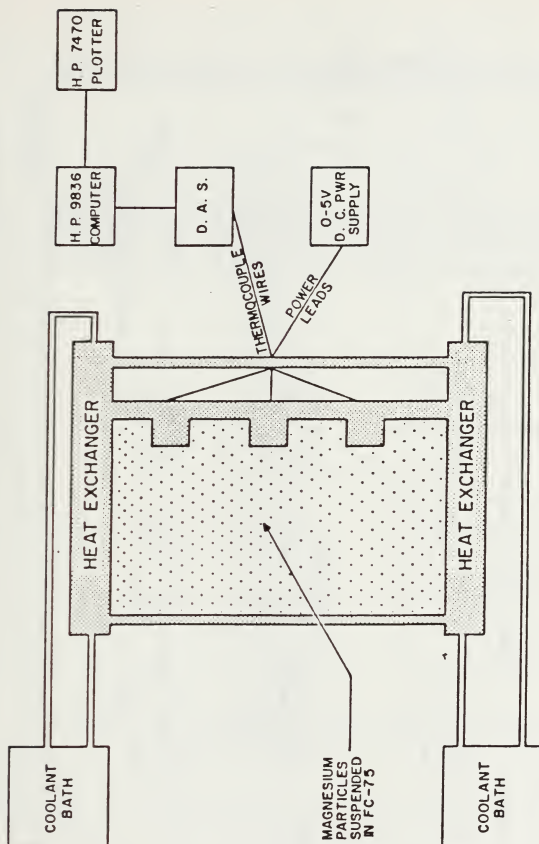
Figure 2.1 Schematic of Entire Assembly

9
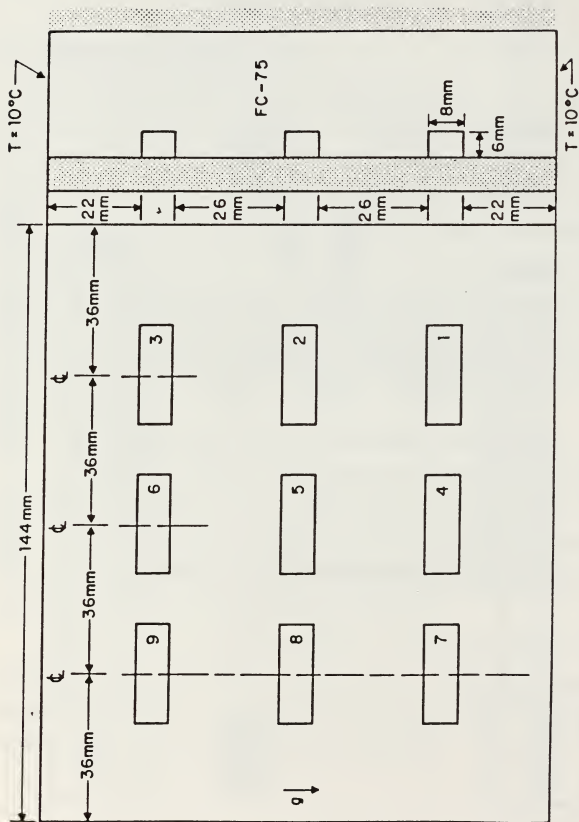
Figure 2.2 Simulated Circuit Card for the Horizontal Arrangement

10
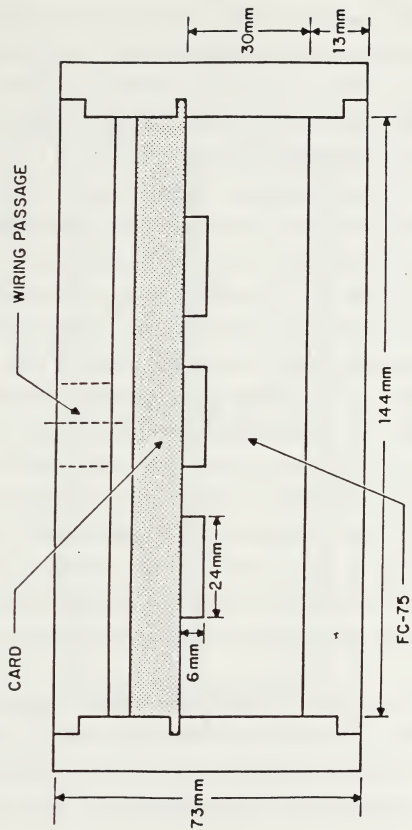
Figure 2.3 Top View of Horizontally Arranged Components Chamber

WIRING PASSAGE

CARD

FC-75

30mm

13mm

144mm

24mm

6mm

73mm

11

2. Experimental Set-Up for the Vertical Arrangement

The chamber assembly, illustrated in Figure 2.4 was made of 19.05 mm plexiglass with dimensions of 241.13 mm length, 152.0 mm height, and 120.65 mm width. As in the first arrangement, the chamber was filled with FC-75, a dielectric fluid through tubing at the bottom of the chamber.

In both experimental configurations, two heat exchangers, one at the top and one at the bottom, were used (see Figure 2.1). The design of the exchangers for the first configuration is described in Joshi, et al. [Ref. 10]. In the second study, several modifications were made to reduce the heat transfer from the outside environment to the colder circulating water. The resulting design is seen in Figure 2.5. The external walls of both top and bottom heat exchangers were made of plexiglass. The walls acting as the top and bottom of the fluid-filled enclosure were aluminum plates 3 mm thick, chosen to provide an almost isothermal surface condition. Inlet and outlet headers were provided for flow distribution. Three thermocouples, symmetrically placed along the plate length, were used for the calculation of the average surface temperatures. The heat exchangers could be accessed easily to block one or more of the channels to reduce the coolant flow rates.

A 3 by 3 array of discrete protrusions, vertically arranged (see Figure 2.6), was mounted on a 19.05 mm thick plexiglass card. The card was slid into the chamber and was kept in location by plexiglass supports that prevented its linear movement as well as rotation.

12
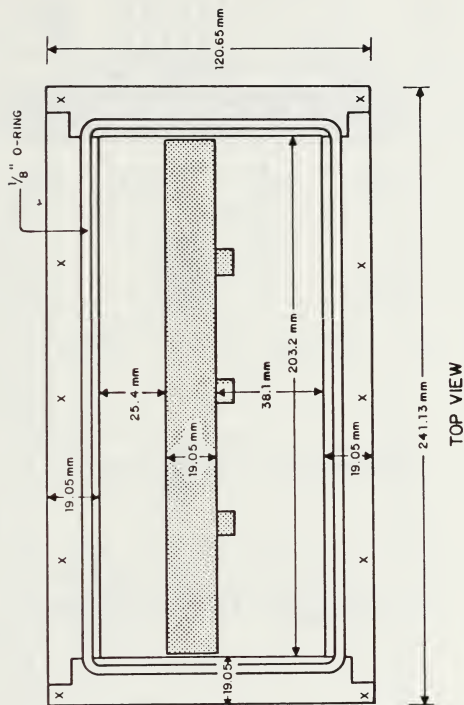
Figure 2.4 Chamber Assembly for the Vertical Arrangement

120.65mm

1/8" O-RING

25.4 mm

19.05 mm

38.1 mm

203.2 mm

19.05mm

19.05 mm

19.05

241.13 mm

TOP VIEW

13
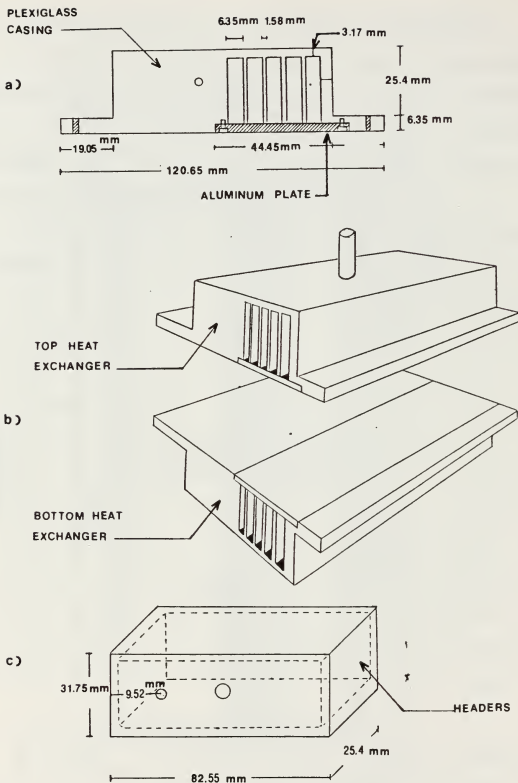
Figure 2.5 **Heat Exchangers**

(a) Cross-Sectional View; (b) Isometric View;
(c) Inlet and Outlet Headers

14
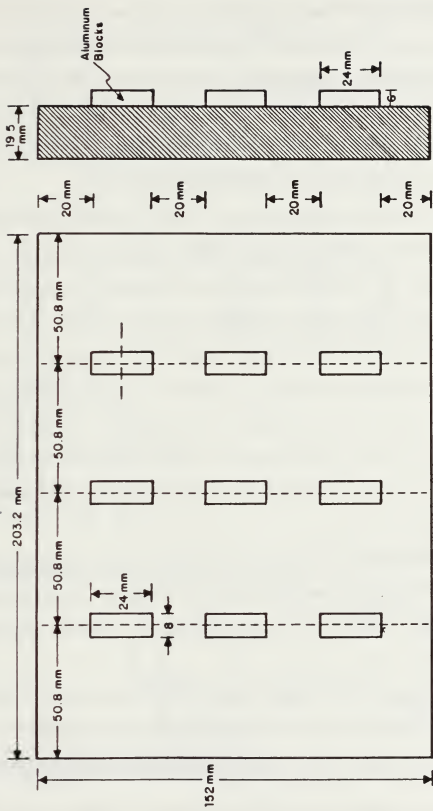
Figure 2.6 Simulated Circuit Card for the Vertical Arrangement

15

The chamber design allowed the replacement of the card in a simple way. The upper heat exchanger could be removed and the new card could be easily installed. This permits the installation of different card configurations (staggered, flush mounted, etc.) in the future without much additional effort. By moving the card back or forth, the chamber width could be changed. This was done in order to study the effect of this parameter in the overall heat transfer.

The heated components in both studies were aluminum blocks of 8 mm by 24 mm and 6 mm high (see Figure 2.7—after Benedict [Ref. 13]). The dimensions and geometry simulate approximately a 20-pin dual-in-line-package. A nearly uniform heat flux condition was maintained at the base of each block by attaching a foil-type heater with a resistance of about 11 ohms. The foil heaters contained a network of Iconel foil mounted on a Kapton backing and were 23.6 mm by 7.6 mm in dimension and were bonded to the base of each aluminum block using a high thermal conductivity epoxy (Omega Bond 101).

Temperatures at the center of each fluid exposed component face were determined using .127 mm diameter copper-constantan thermocouples. Thermocouple locations on each heater are illustrated in Figure 2.7.

All the thermocouples were connected to an HP-3497 automatic data acquisition system controlled by an HP-9826 microcomputer. Power to the heaters was supplied by a 0-40 volt, 0-1A DC

16
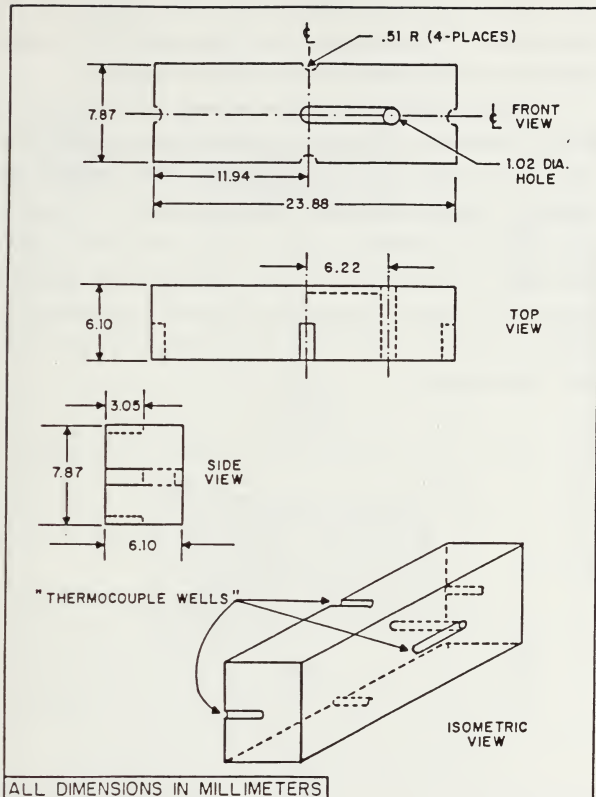
Figure 2.7 **Heating Element and Thermocouple Location**

17

power supply. A simultaneous measurement of the overall voltage drop, along with the voltage drop across each heater, allowed the computation of the power dissipation through individual heaters.

Flow visualization was carried out with a 4 mw Helium-Neon laser for illumination. To produce a plane of light, a cylindrical lens was used (see Figure 2.8—after Benedict [Ref. 13]). The laser sheet illuminated magnesium particles (specific gravity of 1.74) that were added to the FC-75 (specific gravity of 1.76 at 25° C). This technique allowed for the visualization of a single two-dimensional plane of the flow field. Time exposure photographs of the flow were obtained using a Nikon F-3 camera with a 50 mm lens, a MD-4 motor drive, and a MT-2 intervalometer.

CAMERA DEVICE

MAGNESIUM PARTICLES IN FC-75

LIGHT SOURCE

TOP VIEW

MAGNESIUM PARTICLES IN FC-75

PLANE OF LIGHT

LIGHT SOURCE

SIDE VIEW
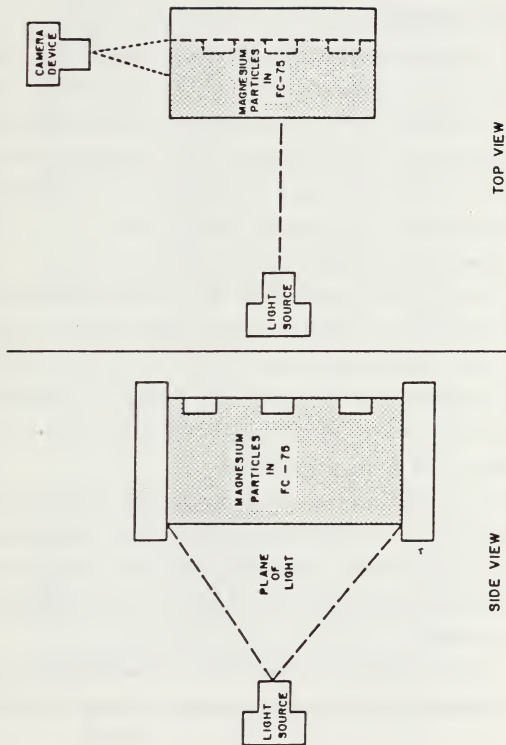
Figure 2.8 Flow Visualization Set-Up

19

III. RESULTS AND DISCUSSIONS
FOR HORIZONTAL ARRANGEMENT

A. FLOW PATTERNS

Flow visualization was carried out in six vertical planes, seen in Figure 3.1 (after Benedict [Ref. 13], for the two different bottom boundary conditions: 20° C and insulated. The three-dimensional transport responses, across the range of power dissipation of 0.1 W to 3.0 W, were inferred from these visualizations. In the following, a detailed description of the observed flows is provided.

1. Flow Patterns for the Bottom Boundary at 20° C

The flow patterns observed at several power dissipation levels from no dissipation to 3.0 W are collected in Figures 3.2 to 3.7. Visualization with no power (see Figures 3.2 and 3.3) was to examine the natural convection flow due only to the difference in temperature between the two heat exchangers, and its possible influence on the flow patterns, with the heaters turned on.

At no power, the flow consisted of a single clockwise cell that occupied the entire chamber. This overall flow was established as a result of the temperature differences between the enclosure walls. The three-dimensionality of the flow was evident from visualizations in the various planes.

At 0.1 W, the pattern observed at no power in Figures 3.2 and 3.3 was completely distorted and no remains of the strong clockwise
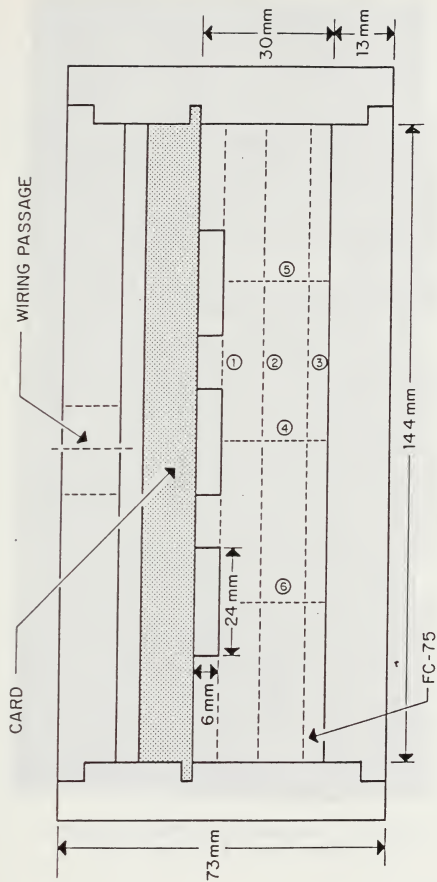
The six vertical flow visualization planes are identified in the sketch.

Figure 3.1 **Top View of the Enclosure With the Card Placed in Position**

21

Figure 3.2 **Visualization With No Power in Planes 1 (a), 2 (b), and 3 (c)**

22
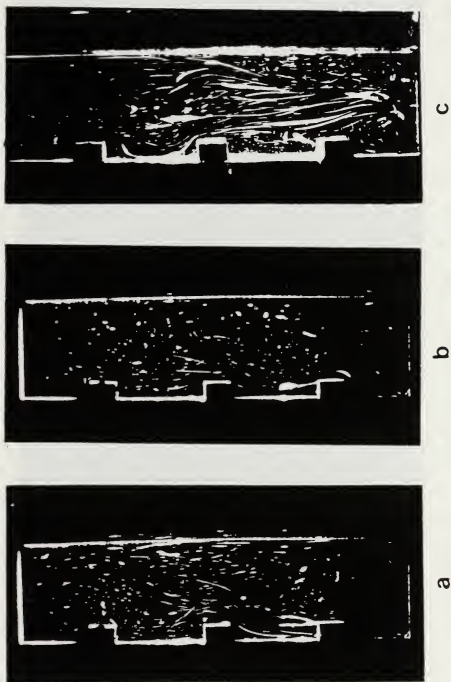
Figure 3.3 Visualization With No Power in Planes 4 (a), 5 (b), and 6 (c)
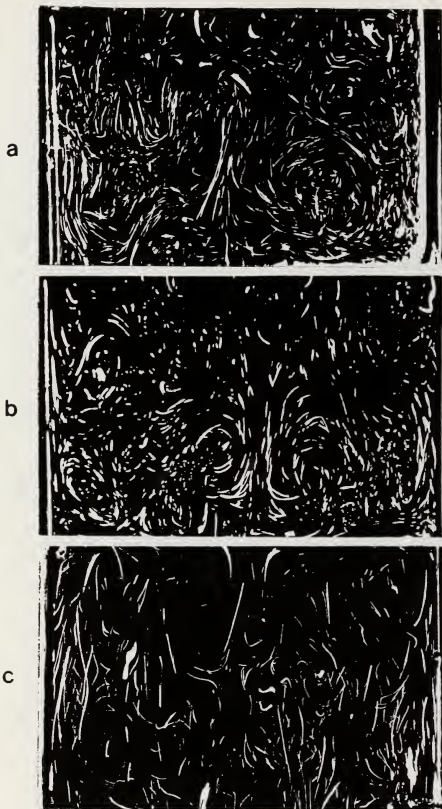
Figure 3.4 **Visualization with 1.1 W in Planes 1 (a), 2 (b), and 3 (c)**

24
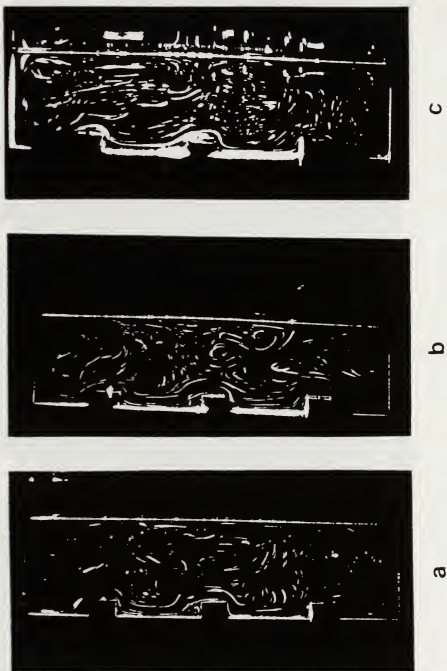
Figure 3.5 Visualization With 1.1 W in Planes 4 (a), 5 (b), and 6 (c)

25
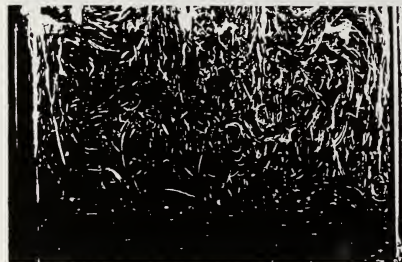
Figure 3.6 **Visualization with 3.0 W in Planes 1 (a), 2 (b), and 3 (c)**

26
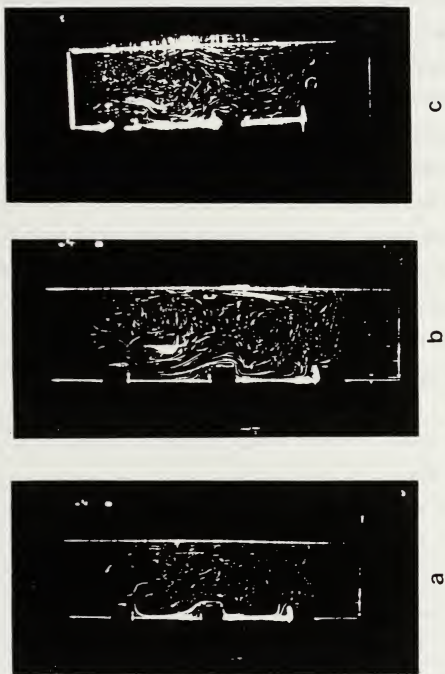
Figure 3.7 Visualization With 3.0 W in Planes 4 (a), 5 (b), and 6 (c)

27

flow were seen. Joshi, et al. [Ref. 10] at the same power level reported two very well defined large clockwise cells, one on each side of the central component column. The present visualization showed that the flow now was completely dominated by the relatively high temperature of the bottom heat exchanger. The effects of the buoyancy forces due to the power dissipation were small except in plane 1 (close to the heaters), where there was a well defined upflow.

In plane 2, the particle traces showed a decrease in velocity. Also, dark regions, as observed in Joshi, et al. [Ref. 10], were seen. These were, however, thinner and not well defined. These nearly quiescent regions appear due to the stable stratification produced by the bottom heat exchanger. Descending fluid from the top is unable to penetrate the colder layer of fluid at the bottom. In plane 3, a downflow resulted due to an increase in the density of the colder fluid, in contact with the upper heat exchanger, at 10° C.

At 1.1 W (see Figure 3.4), a well defined pattern could be observed in planes 1 and 2. Along the central column of heaters, the upflow was wider and stronger than near the adjacent columns. This flow was the result of the interaction of an upflow along the central column, a clockwise flow around the right column (heaters 1, 2, and 3), and a counterclockwise flow around the left column (heaters 7, 8, and 9). In plane 3, a downflow of cold liquid was seen. In Figure 3.5, flow patterns at 1.1 W in planes 4, 5, and 6 are illustrated. It is possible in these pictures to appreciate in a side view the strong upflow adjacent to the components. The basic difference with the flow

28

pattern found in the study by Joshi, et al. [Ref. 10] at the same power level is still that the inactive zone in the bottom of the chamber is not well defined.

With further increase in the power level, the flow in plane 1 exhibited stronger upflow near the components. The buoyancy forces generated by the power dissipation here were strong enough to extend their influence to planes 2 and 3. At 3.0 W, a very thin, dark layer was still observed at the bottom of the chamber (see Figure 3.6). A view of the flow patterns in planes 4, 5, and 6 is illustrated in Figure 3.7. This figure shows a buoyant fluid layer adjacent to the components. In the remaining chamber, the motion was completely random.

2. Flow Pattern With the Bottom Boundary Insulated

The flow pattern for this condition showed similar trends as discussed in section A.1. The induced flow due to the difference in temperature between the two heat exchangers was not appreciable.

B. HEAT TRANSFER MEASUREMENTS

Heat transfer measurements were made at power levels of 0.1, 0.7, 1.1, 1.5, and 3.0 watts for the two bottom surface boundary conditions. The temperature at the top heat exchanger was maintained constant at $10°$ C in all experiments. Temperature and flux-based Rayleigh numbers (Ra_t and Ra_f) were calculated in a manner identical to that discussed in Joshi, et al. [Ref. 10] and plotted versus Nusselt number ($Nu1$). These are defined in the Table of Symbols and Abbreviations.

1. Heat Transfer Measurements With the Bottom Boundary at 20° C

Component surface temperature measurements at various power levels are collected in Tables 1 through 8 in Appendix C. The nondimensional heat transfer parameters in the form of Nusselt versus Rayleigh numbers are illustrated in Figures 3.8 and 3.9. In the same plots, the correlations found by Joshi, et al. [Ref. 10] were also plotted.

We can see that having the bottom heat exchanger at 20° C results in general in lower Nusselt numbers than those found by Joshi, et al. [Ref. 10] in the range of Rayleigh numbers considered. At higher power levels, when the temperature of the heaters was considerably higher than the bulk temperature of the dielectric fluid, the difference in Nusselt numbers is smaller than at lower power levels. The Nusselt number at a flux-based Rayleigh number of 10^6 found by Joshi, et al. [Ref. 10] was 20.4, while the Nusselt number obtained here for the same Rayleigh number was 19. At lower power levels 0.1 W and 0.7 W, the differences in Nusselt number were greater, and the decrease in the heat transfer coefficient was significant. The Nusselt number found by Joshi, et al. [Ref. 10] was 10.5 at a flux-based Rayleigh number of 10^6, while the Nusselt obtained with the present configuration was 2.9.

At power levels of 0.1 W and 0.7 W, a small increase in the upper heaters' temperatures over the lower ones was observed. At higher power levels, the highest temperatures were found irregularly in different components.
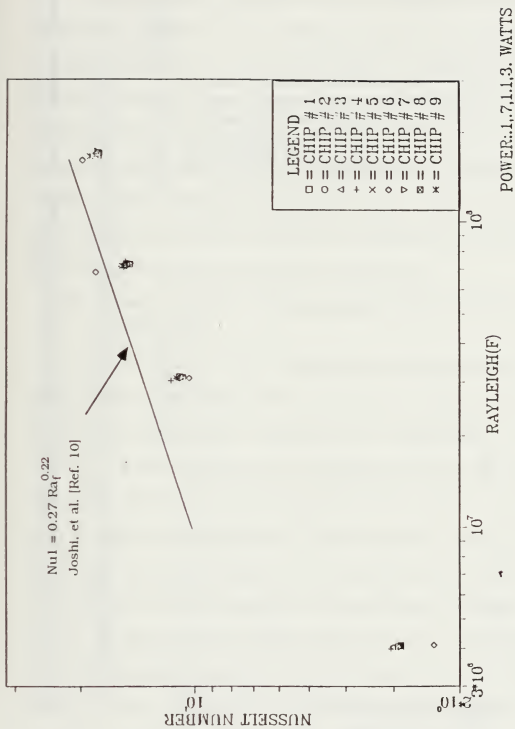
Correlation found by Joshi, et al. [Ref.10] is plotted with a continuous line.

Figure 3.8 **Plot of Flux-Based Rayleigh Number Versus Nusselt Number**

- 31 -
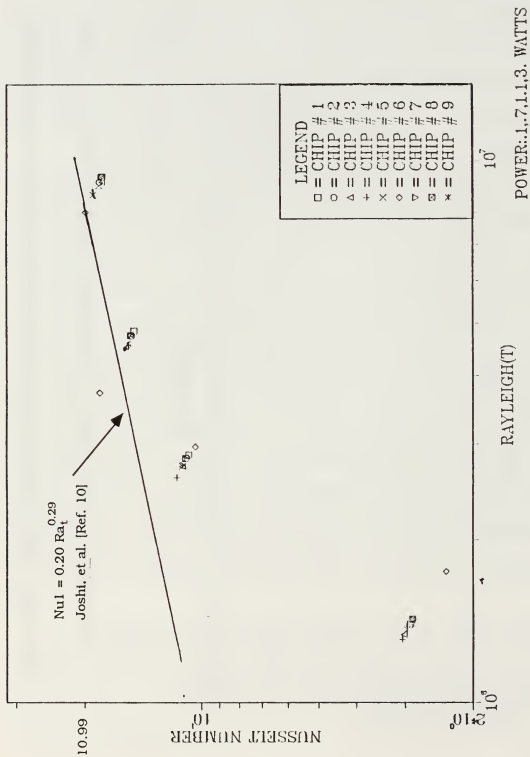
Correlation found by Joshi, et al. [Ref. 10] is plotted with a continuous line.

Figure 3.9 **Plot of Temperature-Based Rayleigh Number Versus Nusselt Number**

32

The component that presented the largest variations from the mean in the heat transfer coefficients was the upper component in the central column (heater 6). This is evidenced as deviations from the general trend of the obtained data. The variations (lower heat transfer coefficient at low power levels, and higher heat transfer coefficients at higher power levels) are expected because this component receives the influence of the combined upflowing streams (produced by the other heaters), as was observed and documented in the flow visualization results in Section A.1. The effect is greater at higher power levels when the component's temperature is substantially larger than the bottom heat exchanger temperature.

2. Heat Transfer Measurements With the Bottom Boundary Insulated

The results of the temperature measurements with the bottom boundary insulated and the reduced dimensionless parameters are collected in Tables 9 through 16 in Appendix C. In Figures 3.10 and 3.11, flux and temperature Rayleigh numbers versus Nusselt numbers were plotted. Correlations found by Joshi, et al. [Ref. 10] were also plotted for comparison. It was seen that having the bottom heat exchanger insulated improved the cooling at low power levels (0.1 W and 0.7 W) over that obtained with the bottom boundary maintained at 20° C. This result is expected because now the temperature of the bottom boundary was 15° C at 0.1 W and 17° C at 0.7 W. At a power level of 3.0 W, no cooling improvement was observed. The temperature for the bottom boundary at 3.0 W was 22° C.
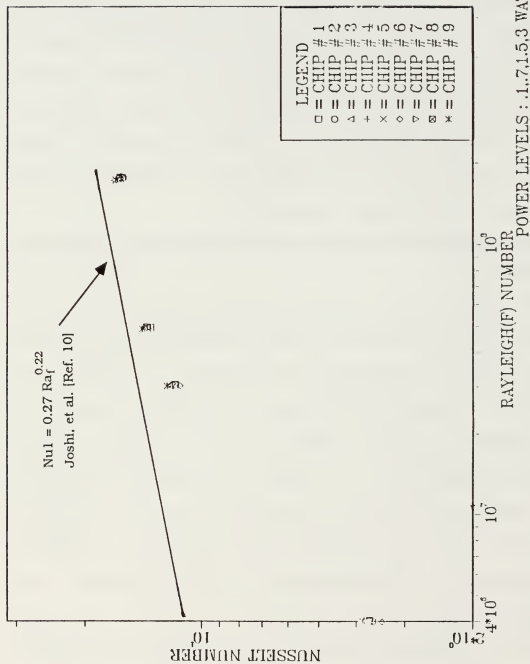
Correlation found by Joshi, et al. [Ref.10] is plotted with a continuous line.

Figure 3.10 Plot of Flux-Based Rayleigh Number Versus Nusselt Number

34
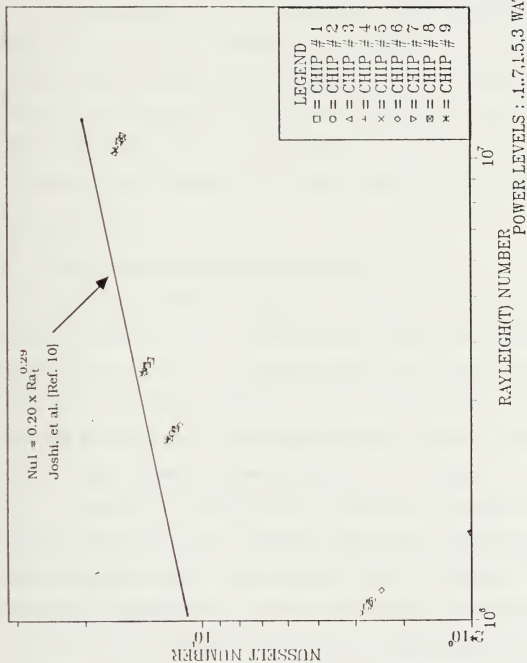
Correlation found by Joshi, et al. [Ref. 10] is plotted with a continuous line.

Figure 3.11 Plot of Temperature-Based Rayleigh Number Versus Nusselt Number

35

Comparisons with the correlation obtained by Joshi, et al. [Ref. 10] show a decrease in the heat transfer coefficient when the lower boundary was insulated. This was evidenced by the lower Nusselt numbers at all power levels.

IV. RESULTS AND DISCUSSIONS FOR VERTICAL ARRANGEMENT

A. FLOW VISUALIZATION

The visualization for this experiment was tried for a chamber width of 9 mm. As was expected, there was almost no flow in the narrow gap between components and the front wall. A boundary layer-like behavior was observed on the vertical side faces of the components. The photography process was complicated because the thickness of the plane to be illuminated by the laser sheet for this chamber width was only 3 mm.

B. HEAT TRANSFER MEASUREMENTS

Component surface temperature measurements were made for chamber widths of 30 mm and 9 mm (see Figure 4.1). The power level range was 0.1 W to 3.0 W. Temperatures of the top and bottom boundaries were maintained constant at 10° C. Plots of Nul versus Ra_f are provided for comparisons with data obtained by Benedict [Ref. 13].

1. Heat Transfer Measurement for w = 30 mm

Tables 17 through 28 in Appendix C compile component surface temperature and resulting nondimensional heat transfer data for this gap size with increasing power levels. The mean values of the component averaged temperatures over the nine heated components were 13° C for 0.1 W and 47° C for 3.0 W. In the range 0.1 W to 1.1 W, the lowest T_{avg} levels were on the bottom-row components

37
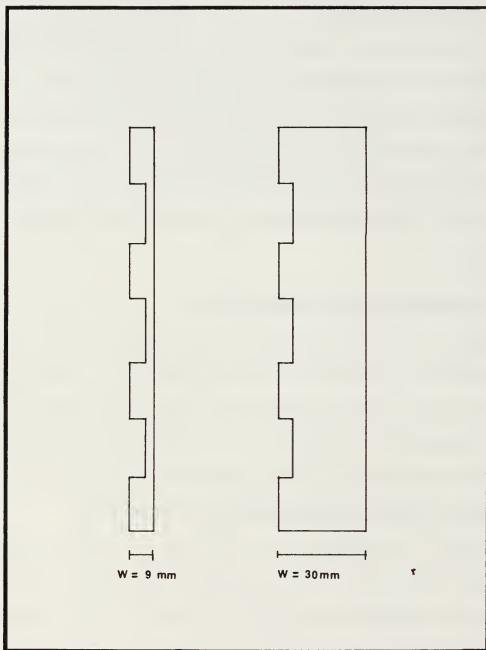
Figure 4.1 **Side View Showing the Chamber Widths Used in the Experiment**

(components 1, 4, and 7). The observed tendency was that temperatures on specific locations on the components in the top row were higher than those in the same location on the components in lower rows. As was pointed out by Liu, et al. [Ref. 11], the possible reason for this might be that components in the top row are in contact with warmer liquid, and the upper-row components are located in the heated wake regions of the lower rows. Additionally, the stratified fluid away from the components, which feeds fluid toward the component rows, is also at higher temperature for the upper rows.

Analyzing individual components in the middle and lower rows, for all power levels, the minimum measured temperatures were on the bottom surfaces. This trend is also supported by Liu, et al. [Ref. 9]. On the top row components, the lowest temperatures were on either one of the vertical side faces. Maximum temperatures were found generally on the component surface facing the front chamber wall. Liu, et al. [Ref. 11] obtained numerically maximum temperatures in the surfaces facing upward and attributed this to the fact that the heated flow coming off the vertical surfaces reduced the heat transfer coefficient at the component top surface. At higher power levels, oscillations in temperature changed the locations of the maximum and minimum instantaneous values, but the general tendencies found earlier were still noticed.

In Figure 4.2, a plot of $Nu1$ versus Ra_f is seen. Data obtained from Benedict [Ref. 13] is also plotted. A linear least squares fit to the present measurements in Figure 4.2 was performed. This is given by:
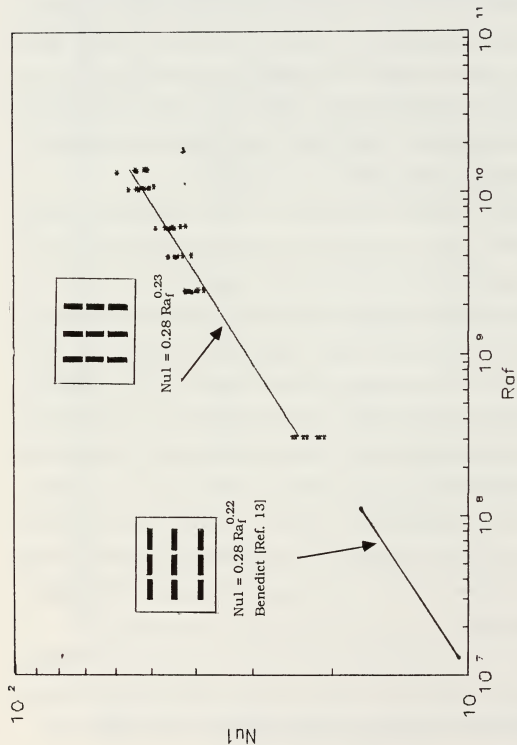
The curve fit for the horizontal arrangement is from Benedict [Ref. 13]. Present measurements and curve fit are for the vertical arrangement.

Figure 4.2 Comparison of the Nondimensional Heat Transfer Measurements for Two Different Component Orientations

40

$$Nu1 = 0.28 \, Ra_f^{0.23} \text{ in the range } 3 * 10^8 < Ra_f < 10^{10}$$

$$\text{and } 15 < Pr < 30.2 \tag{4.1}$$

and the one obtained with the data from Benedict [Ref. 13] was:

$$Nu1 = 0.28 \, Ra_f^{0.22} \text{ in the range } 10^7 < Ra_f < 2 * 10^8$$

$$\text{and } 15 < Pr < 30.2 \tag{4.2}$$

Comparisons between Equations 4.1 and 4.2 indicate that Nu appears not to depend on the orientation of the components in the range of Ra_f and Pr considered. This is illustrated in Figure 4.2

2. Heat Transfer Measurement for w = 9 mm

In Tables 29 through 40 in Appendix C, component temperatures and resulting nondimensional heat transfer data are compiled. Decreasing the chamber width from 30 mm to 9 mm produced some increase in the average temperature of the components T_{avg}. This behavior was expected considering that now the surface of both top and bottom heat exchangers has been reduced to 30 percent of its former value. The mean value of the component averaged temperatures over the nine heaters for a power of 0.1 W was 14.5° C, 1.5° C higher than the average temperature obtained with 30 mm width. For a dissipation level of 3.0 W, the mean value of the components' averaged temperature over the nine heaters was 51° C, 4.0° C higher than the average observed for the 30 mm width. The T_{avg} value increased from the bottom to the top row, as was also found for w = 30 mm.

41

Analyzing individual components on the bottom row (components 1, 4, and 7), minimum temperatures were found on the bottom surfaces.

Plots of Nu1 versus Ra_f are illustrated in Figure 4.3. The correlation obtained for this chamber width was:

$$Nu1 = 0.073 \, Ra_f^{0.28} \text{ in the range } 3 * 10^8 < Ra_f < 10^{10}$$

$$\text{and } 15 < Pr < 30.2 \qquad (4.3)$$

This correlation indicates the expected decrease in Nu1 for the same Ra_f, when compared with Equation 4.1 for w = 30 mm.

C. TEMPERATURE FLUCTUATIONS IN STEADY STATE

Oscillations in component surface temperatures following achievement of nominally steady conditions were measured in the dissipation range of 0.1 W to 3.0 W. Three thermocouples were scanned at a rate of approximately three times per second for a period of 200 seconds. Plots of surface temperature variations were made in order to display the long-time temperature fluctuations and compare with results of Liu, et al. [Ref. 11] and Benedict [Ref. 13]. Figure 4.4 is a vertical arrangement diagram which portrays the location of the scanned thermocouples.

1. Surface Temperature Fluctuations for a w = 30 mm

Temperature oscillations for this chamber width are illustrated in Figures 4.5 through 4.7. It was observed that at all power
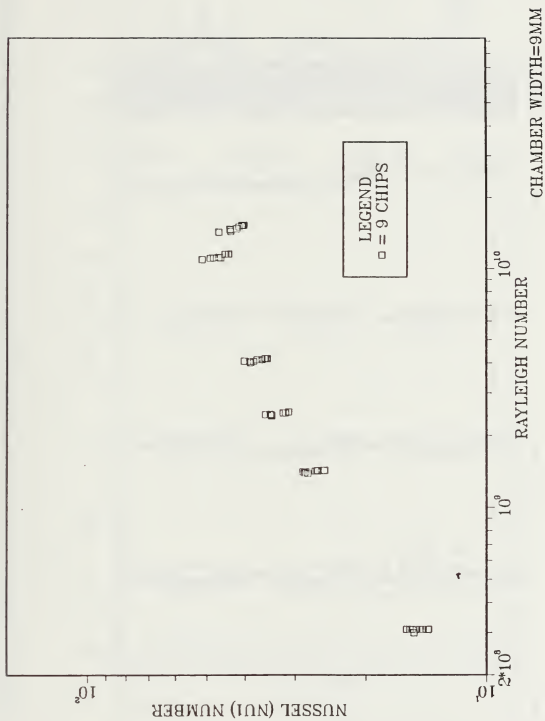
Figure 4.3 Plot of Nu1 vs. Ra$_f$ for a Chamber Width = 9 mm

43

Figure 4.4 Location of Thermocouples Scanned for Measurements of Fluctuations

44
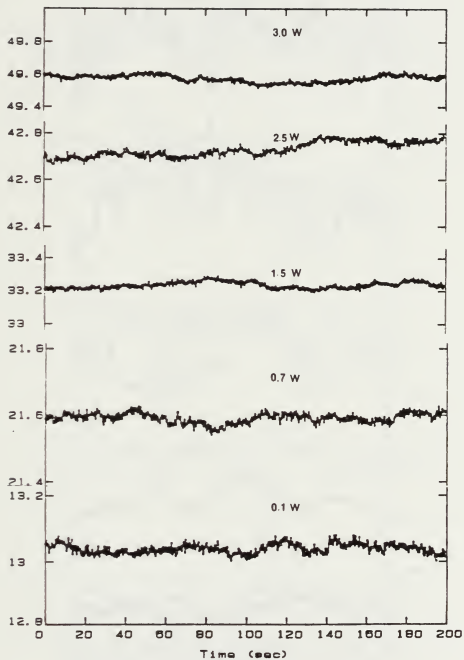
Figure 4.5 **Temperature Fluctuations for Thermocouple No. 0 at Different Power Levels**

45
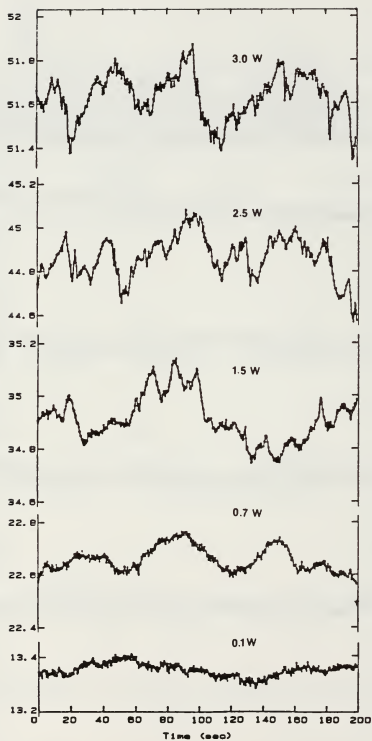
Figure 4.6 **Temperature Fluctuations for
Thermocouple No. 12 at Different Power Levels**
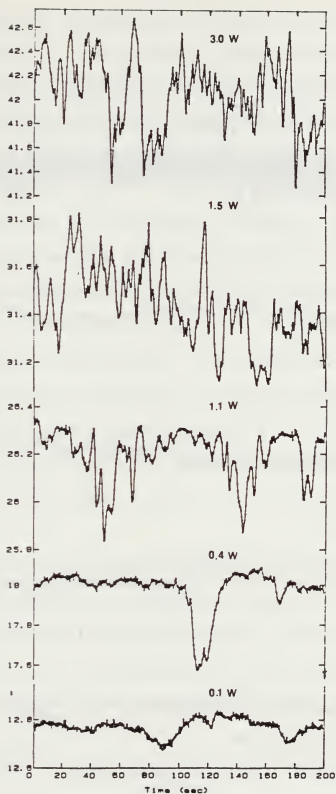
Figure 4.7 Temperature Fluctuations for
Thermocouple No. 31 at Different Power Levels

47

levels considered, there were no temperature fluctuations on the components in the lower row. Benedict [Ref. 13] documented with heat transfer measurement and flow visualizations that the stagnant fluid layer above the bottom heat exchanger prevented the penetration of warmer fluid, resulting in conduction-dominated transport for the bottom row of components.

At 0.1 W, a spread in temperature of less than 0.5° C was observed between the six thermocouples that were scanned. Increasing the power level to 0.7 W, oscillation amplitudes with a mean of 0.7° C were observed in component 6. At 1.1 W, the amplitude increased to 0.8° C. Benedict [Ref. 13] found that a component at the same relative location and power level in a horizontal arrangement had almost no oscillations. At 2.5 W, oscillations of about 1.6° C were found. At 3.0 W, oscillations rose to almost 1.7° C at the same location. Benedict [Ref. 13] found at 3.1 W for the equivalent thermocouple an amplitude of 0.85° C.

2. Surface Temperature Fluctuations for w = 9 mm

Plots of temperature oscillations are illustrated in Figures 4.8 through 4.10. At 0.1 W, no fluctuations were found in any of the thermocouples scanned. At 0.4 W, fluctuations of 0.3° C were observed in the top row components. No fluctuations were observed in the middle and bottom row components.

Increasing the power dissipation level to 0.7 W, no fluctuations were observed in either the middle or the bottom rows, but
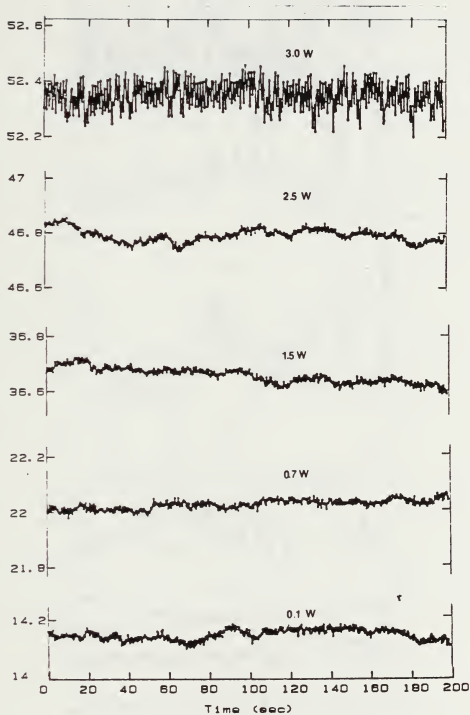
Figure 4.8 **Temperature Fluctuations for Thermocouple No. 0 at Different Power Levels**
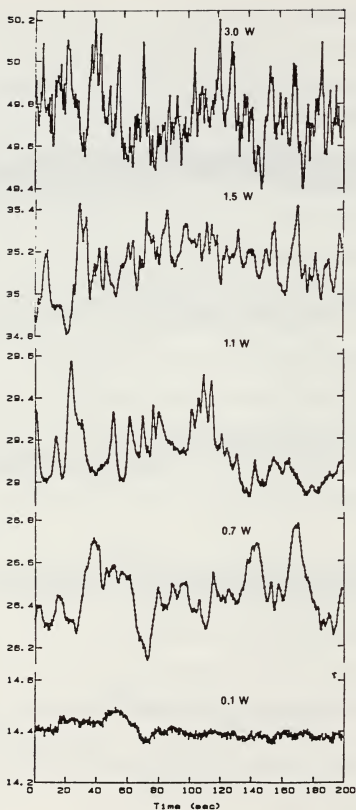
Figure 4.9 **Temperature Fluctuations for
Thermocouple No. 12 at Different Power Levels**
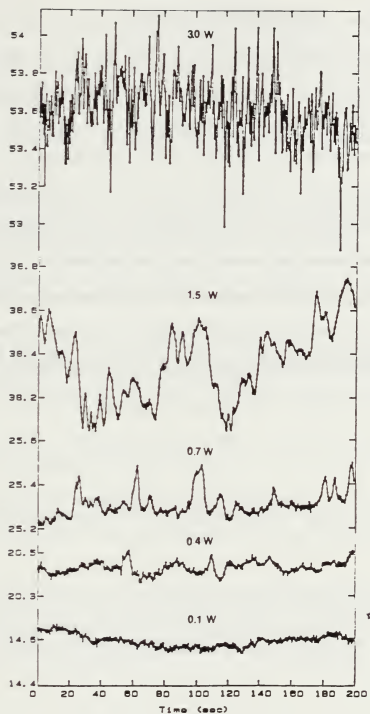
Figure 4.10 **Temperature Fluctuations for Thermocouple No. 31 at Different Power Levels**

51

fluctuations of 0.7° C were observed in the top row. At 1.1 W, fluctuations in the top-row components were about 0.9° C. No fluctuations were observed at the middle and bottom rows. At 1.5 W, fluctuations of 0.2° C appeared in the components in the middle row and reached values of 1.1° C in the top-row components. At 3.0 W, the highest power level utilized in the experiments, fluctuation amplitudes on the top-row components were recorded at 2.0° C. It is interesting to note that no significant increase in the amplitude of the fluctuations was observed when the chamber width was changed from 30 mm to 9 mm. Liu, et al. [Ref. 11] calculated temperature oscillations peak to valley of 8° C for the 9 mm chamber width. They attributed the increase in the oscillation amplitude to the fact that now the flow is highly confined.

V. RECOMMENDATIONS

The design of the present chamber can be improved in many ways to give more versatility in the following experiments. The recommended changes that can be made to software and hardware include:

- Placement of the blocks can be done by screwing or attaching them to the board in a different way to the one used until now, which is bonding the chips to the board with glue. This would allow the experimenter to change a defective heater or change the orientation of the chips for a different set of experiments, using the same board and the same equipment set-up.

- To avoid the flow of dielectric liquid to the back of the chamber through the gaps between the board and the chamber walls that can alter the heat transfer results or the flow visualization, a small diameter O-ring can be used. A groove should be engraved in the board to allow the O-ring installation.

- Temperature measurements within the fluid and on the board surfaces should also be performed.

- a Fast Fourier Transform algorithm should be developed to perform frequency analysis on the surface temperature fluctuations data. In addition, improvements in the plotting programs can be made.

- With the present set-up, different combinations of heaters could be powered, row-wise or column-wise or staggered, instead of the entire array. This variation might help better to explain the heat transfer and flow characteristics of the chamber.

SAMPLE CALCULATIONS

A. CONVERSION OF THERMOCOUPLE VOLTAGES TO TEMPERATURES

(Channels 0 to 60 and 71 to 76, in the data acquisition system)

$$T = D1 + D2 * Emf + D3 * Emf^2 + D4 * Emf^3 + D5 * Emf^4 + D6 * Emf^5 + D7 * Emf^6 + D8 * Emf^7$$

where D1 to D9 are the calibration coefficients of the Omega thermo-couples and are: 0.10086091, 25727.9, -767345.8, 7802-5596, -9247486589, 6.98E11, -2.66E13, and 3.94E14.

Calculating the temperature found in the thermocouple connected to channel 0 at 1.1 W gives:

$$Emf = 0.995E\text{-}3 \text{ V}$$
$$T = 24.48° \text{ C}$$

B. CALCULATION OF HEATER POWER

Channels 61 to 70 in the data acquisition system are used to measure the supply voltage (61) and voltage to the heaters.

$$Power = Emf * (Volt - Emf)/Rp$$

Calculating the power dissipated by the heater #3:

$$\text{Power} = 3.408 * (4.085 - 3.408)/2.07$$
$$\text{Power} = 1.114 \text{ W}$$

C. CALCULATION OF THE DIMENSIONLESS PARAMETERS

1. Calculation of the Block Faces Areas

Dimensions of the aluminum blocks are: length 24 mm, width 8 mm, and thickness 6 mm.

$$A_{cen} = 24 \text{ mm} * 8 \text{ mm} = 192 \text{ mm}^2 = 1.92\text{E-4 m}^2$$
$$A_{lef} = 24 \text{ mm} * 6 \text{ mm} = 144 \text{ mm}^2 = 1.44\text{E-4 m}^2$$
$$A_{rig} = 24 \text{ mm} * 6 \text{ mm} = 144 \text{ mm}^2 = 1.44\text{E-4 m}^2$$
$$A_{top} = 6 \text{ mm} * 8 \text{ mm} = 48 \text{ mm}^2 = 4.8\text{E-5 m}^2$$
$$A_{bot} = 6 \text{ mm} * 8 \text{ mm} = 48 \text{ mm}^2 = 4.8\text{E-5 m}^2$$
$$A_{tot} = \Sigma A = 576 \text{ mm}^2 = 5.76\text{E-4 m}^2$$
$$T_{avg} = \Sigma(T(I) * A(I))/A_{tot}$$

Calculating for component 3 at 1.1 W:

$$T_{avg} = (27.67 * 1.92\text{E-4} + 25.73 * 4.8\text{E-5} + 26.08$$
$$* 1.44\text{E-4} + 26.69 * 4.8\text{E5}) \quad /5.76\text{E-4}$$
$$T_{avg} = 26.63° \text{ C}$$

2. Calculation of the Temperatures at the Back of the Components

Due to problems in the placement of the thermocouples that measure the temperature at the heaters, these temperatures were calculated with a calibration curve for w = 30 mm from data obtained in Benedict [Ref. 13]. This calibration cannot be applied to the case where the width of the chamber is very small. In such a case, when w = 9 mm, a one-dimensional conduction analysis was applied to find the back temperature.

The best fit for the calibration points was:

$$T(K) = 14.003957 * Power + 14.517501$$

So, for 1.1 W,

$$T = 29.92° C$$

3. To Calculate the Conduction Losses Through the Circuit Card

$$Q_{loss} = \Delta T/Rc = 1/N \; \Sigma(T(I) - Tb(J))/Rc$$

$R_c = L/kA$

$R_c = 19.5E-3/(0.195 * 8E-3 * 24E-3) = 520.83 \; K/W$

$L = 19.5E-3 \; m$

$k = 0.195 \; W/m.K$ (plexiglass conductivity [Ref. 14])

$A = (24E-3 * 8E-3) \; m^2 = 1.92E-4 \; m^2$

$Q_{loss} = (29.92 - 17.31)/520.83$

$\qquad = 0.024 \; W$

4. To Find the Average Sink Temperature

Channels 58, 59, and 60 in the bottom heat exchanger and channels 61, 72, and 73 in the top heat exchanger.

$$T_{sink} = 1/N \ (\Sigma T_{tc} + \Sigma T_{bc})$$
$$T_{sink} = (10.05 + 10.1 + 10.02 + 10.11 + 10.12 + 10.13)/6$$
$$T_{sink} = 10.08° \ C$$

To find the net power dissipated by the heater, Q_{net}:

$$Q_{net} = Power - Q_{loss}$$

For 1.1 W and component 3:

$$Q_{net} = (1.1 - 0.024) \ W$$
$$= 1.076 \ W$$

To find the convection coefficient h (from Newton's law of cooling):

$$Q_{net} = h * A_{tot} * \Delta T$$
$$\Delta T = T_{avg} - T_{sink}$$
$$\Delta T = (26.63 - 10.08)° \ C$$
$$T = 16.55° \ C$$
$$h = Q_{net} \ /(A_{tot} * \Delta T)$$

5. For 1.1 W and Component 3

$$h = 1.09 \ /(16.55 * 5.76E-4)$$
$$h = 114.342 \ W/m^2 \ K$$

6. **To Calculate the Thermal Conductivity of the FC-75**

$$k = (0.65 - 7.8947E-4 * T_{film})/10$$

where $T_{film} = (T_{avg} + T_{sink})/2$.

At 1.1 W and chip 3:

$$T_{film} = (26.63 + 10.08)° \text{ C}/2$$
$$T_{film} = 18.35° \text{ C}$$
$$k = 0.0645 \text{ W/m K}$$

7. **To Calculate the Vertical Length Based Nusselt Number, Nu1**

$$Nu1 = h * L1/k$$
$$Nu1 = 114.342 * 24E-3/0.0645$$
$$Nu1 = 42.54$$

8. **To Calculate the Ratio Area/Perimeter Based Nusselt Number, Nu2**

$$L2 = \Sigma(A(i)/P(i))$$
$$L2 = (24 * 8)/64 + (2 * 8 * 6)/(2 * 14) + (2 * 24 * 6)/(2 * 60)$$
$$L2 = 11.229E-3 \text{ m}$$
$$L2 = 19.905$$

9. To Calculate the Density of the FC-75, ρ (Kg/m^3)

$\rho = (1.825 - 0.00246 * T_{film}) * 1000$

$\rho = 1779.86 \text{ Kg/m}^3$

10. To Calculate the FC-75 Specific Heat, Cp (J/Kg K)

$Cp = (.241111 + 3.7037E-4 * T_{film}) * 4180$

$Cp = 1036.25 \text{ J/Kg K}$

11. To Calculate the FC-75 Viscosity, $\nu(\text{m}^2/\text{s})$

$\nu = (1.4074 - 2.964E-2 * T_{film} + 3.8018E-4$
$\quad * T_{film}^2 - 2.7308E-6 * T_{film}^3 + 8.1679E-9 * T_{film}^4)E-6$

$\nu = .97557E-6 \text{ m}^2/\text{s}$

12. To Find the FC-75 Thermal Expansion Coefficient, $\beta(\text{K}^{-1})$

$\beta = 0.00246/(1.825 - 0.00246 * T_{film})$

For 1.1 W and component 3:

$\beta = 1.382E-3 \text{ K}^{-1}$

13. To Calculate the FC-75 Thermal Diffusivity $\alpha(\text{m}^2/\text{s})$

$\alpha = k/\rho * Cp$

For 1.1 W and component 3:

$$\alpha = 3.497E\text{-}8 \ m^2/s$$

14. To Calculate the Grashof Number

$$Gr = g * \beta * 1^3 * \Delta T/\nu^2$$

For 1.1 W and component 3:

$$Gr - 3255734.402$$

15. To Calculate the Prandtl Number

$$Pr = \nu/\alpha$$
$$Pr = 27.89$$

16. To Find the Temperature Based Rayleigh Number

$$Ra = Gr * Pr$$

For 1.1 W and component 3:

$$Ra = 9.08E7$$

17. To Calculate the Flux Based Rayleigh Number

$$Ra_f = g * B * 1^4 * Q_{net}/(k * \nu * \alpha * A_{tot})$$
$$Ra_f = 3.9E9$$

APPENDIX B
UNCERTAINTY ANALYSIS

The uncertainty analysis was done using the method of Kline and McClintock, presented in Holman [Ref. 15]. The calculations will be done for the end values 0.1 W and 3.0 W, for a chamber width of 30 mm.

A. UNCERTAINTIES IN THE NET POWER ADDED TO THE FLUID

$$Q_{net} = Power - Q_{loss}$$

$$Power = emf(I) * (Volt - emf(I))/Rp$$

$$Power = f(emf(I), Volt, Rp)$$

$$\frac{\partial Power}{\partial emf(I)} = \frac{Volt - 2 \cdot emf(I)}{Rp}$$

$$\frac{\partial Power}{\partial Volt} = \frac{emf(I)}{Rp}$$

$$\frac{\partial Power}{\partial Rp} = -\frac{emf(I) \cdot (Volt - emf(I))}{Rp^2}$$

$$W_{power} = \left[\left(\frac{\partial_{power}}{\partial_{emf(I)}} \right)^2 W_{emf(I)}^2 + \left(\frac{\partial_{power}}{\partial_{Volt}} \right)^2 W_{Volt}^2 + \left(\frac{\partial_{power}}{\partial_{Rp}} \right)^2 W_{Rp}^2 \right]^{\frac{1}{2}}$$

61

$$W_{\text{emf}} = 0.001 \text{ V}$$

(by Resolution in the reading and precision of measuring devices)

$$W_{\text{Volt}} = 0.001 \text{ V}$$

(by Resolution in the reading and precision of measuring devices)

$$W_{\text{Rp}} = 0.05 \ \Omega$$

(including the added resistances)

For 0.1 W and chip 3:

$$\text{emf(I)} = 1.022 \text{ V}$$

$$\text{Volt} = 1.225 \text{ V}$$

$$\text{Rp} = 2.06 \ \Omega$$

(measured resistance including resistances in the junctions, etc.)

$$\frac{\partial \text{Power}}{\partial \text{emf(I)}} = -0.397$$

$$\frac{\partial \text{Power}}{\partial \text{Volt}} = 0.496$$

$$\frac{\partial \text{Power}}{\partial \text{Rp}} = -0.0488$$

$$W_{\text{power}} = \left[(-0.397)^2 \cdot (0.001)^2 + (0.496)^2 \cdot (0.001)^2 + (-0.0488)^2 \cdot (0.05)^2 \right]^{\frac{1}{2}}$$

$$W_{power} = 0.00252 \text{ W}$$

$$\frac{W_{power}}{Power} = \frac{0.00252 \text{ W}}{0.1 \text{ W}} = 2.5\%$$

$$Q_{loss} = \frac{\Delta T}{Rc}$$

where ΔT is the difference in temperature between the back surface of the chip and the back of the board.

$$Q = f(\Delta T, \ Rc)$$

$$\frac{\partial Q_{loss}}{\partial \Delta T} = \frac{1}{Rc} = \frac{Q_{loss}}{\partial Rc} = \frac{\Delta T}{Rc^2}$$

For 0.1 W and component 3:

$$\frac{\partial Q_{loss}}{\partial \Delta T} = \frac{1}{520.83 \text{ K/W}} = 0.00192$$

$$\frac{\partial Q_{loss}}{\partial Rc} = -\frac{0.12^\circ \text{ K}}{(520.83)^2} = -4.424 \times 10^{-7}$$

$$WQ_{loss} = \left| \left(\frac{1}{Rc}\right)^2 W_{\Delta T} + \left(\frac{-\Delta T}{Rc^2}\right) W_{Rc} \right|$$

$$W_{\Delta T} = 10\% = 0.012^\circ \text{ C}$$

63

$$W_{Rc} = 10\% = 52.083 \text{ K/W}$$

$$WQ_{loss} = \left[(0.00192^2 \cdot 0.012^2 + \left(-4.424 \times 10^{-7}\right)^2 \cdot (52.083)^2\right]^{\frac{1}{2}}$$

$$WQ_{loss} = \left(5.352 \times 10^{-10}\right)^{\frac{1}{2}} = 3.258\text{E}{-5}$$

$$\frac{WQ_{loss}}{Q_{loss}} = 0.14 = 14\%^{1}$$

$$WQ_{net} = \left[\left(W_{power}\right)^2 + \left(WQ_{loss}\right)^2\right]^{\frac{1}{2}}$$

$$WQ_{net} = \left[(0.00252)^2 + \left(3.258 \times 10^{-5}\right)^2\right]^{\frac{1}{2}}$$

$$WQ_{net} = \pm 0.025 \text{ W}$$

$$\frac{WQ_{net}}{Q_{net}} = \pm 2.5\%$$

---

[1]The uncertainties in the losses are relatively big, but they do not have a large effect on the final undertaking.

64

For 3.0 W and component 3:

$$emf(I) = 5.647 \text{ V}$$

$$Volt = 6.762$$

$$Rp = 2.06\Omega$$

$$\frac{\partial \text{Power}}{\partial \text{emf}(I)} = -2.2$$

$$\frac{\partial \text{Power}}{\partial \text{Volt}} = 2.74$$

$$\frac{\partial \text{Power}}{\partial \text{Rp}} = 1.484$$

$$W_{power} = \left[(-2.2)^2 \cdot (0.001)^2 + (2.74)^2 \cdot (0.001)^2 + (1.484)^2 \cdot (0.05)^2 \right]^{\frac{1}{2}}$$

$$W_{power} = 0.74 \text{ W}$$

$$\frac{W_{power}}{power} = \frac{0.074}{3.0} = \pm 2.5\%$$

$$\frac{\partial Q_{loss}}{\partial \Delta T} = \frac{1}{520.83} \text{k/w} = 0.00192$$

$$\frac{\partial Q_{loss}}{\partial Rc} = -\frac{21.68}{(520.83)^2} = -7.993E-5$$

65

$$WQ_{loss} = \left[(0.00192)^2 \cdot (2.168)^2 + (-7.992E-5)^2 \cdot (52.083)^2 \right]^{\frac{1}{2}}$$

$$WQ_{loss} = 0.059 \text{ W}$$

$$\frac{WQ_{loss}}{Q_{loss}} = 14.14\%$$

$$WQnet = \left[\left(W_{power} \right)^2 + \left(WQ_{loss} \right)^2 \right]^{\frac{1}{2}}$$

$$WQnet = \left[(0.074)^2 + (0.0059)^2 \right]^{\frac{1}{2}}$$

$$WQ_{net} = \pm 0.0742 \text{ W}$$

$$\frac{WQ_{net}}{Q_{net}} = \pm 2.5\%$$

B. UNCERTAINTY IN RAYLEIGH AND NUSSELT NUMBERS

Starting with:

$$Q_{net} = hA_{tot} (T_{avg} - T_{sink})$$

$$h = \frac{Q_{net}}{A_{tot}(T_{avg} - T_{sink})}$$

66

$$h = f(Q_{net}, A_{tot}, \Delta T)$$

$$\frac{\partial h}{\partial Q_{net}} = \frac{1}{A_{tot}(\Delta T)}$$

$$\frac{\partial h}{\partial A_{tot}} = \frac{Q_{net}}{A_{tot}(\Delta T)^2}$$

$$\frac{\partial h}{\partial \Delta T} = \frac{Q_{net}}{A_{tot}(\Delta T)^2}$$

for 0.1 W and component 3:

$$A_{tot} = 5.76 \times 10^{-4} m^2 \text{ (for all components)}$$

$$\frac{\partial h}{\partial Q_{net}} = \frac{1}{(5.76 \times 10^{-4})(3.02)} = 574.87$$

$$\frac{\partial h}{\partial A_{tot}} = \frac{0.1}{(5.76 \times 10^{-4})(3.02)} = -99804.03$$

$$\frac{\partial h}{\partial \Delta T} = -\frac{-0.1}{(5.76 \times 10^{-4})(3.02)^2} = -19.035$$

$$Wh = \left[\left(\frac{\partial h}{\partial Q_{net}}\right)^2 WQ_{net}^2 + \left(\frac{\partial h}{\partial \Delta_{tot}}\right)^2 W_{A_{tot}}^2 + \left(\frac{\partial h}{\partial \Delta T}\right)^2 W_{\Delta T}^2\right]^{\frac{1}{2}}$$

$$WQ_{net} = \pm 0.0025 \text{ W}$$

$$W_L = \pm 10^{-5} \text{ m}$$

$$W_A = \left[\left(10^{-5} \right)^2 + \left(10^{-5} \right)^2 \right]^{\frac{1}{2}} = 1.41\text{E}{-5} \text{ m}^2$$

$$W_{\Delta T} = \pm 1\% = 0.03° \text{ C}$$

$$W_h = \left[(574.87)^2 \cdot (0.0025)^2 + (99804)^2 \cdot (1.41\text{E}{-5})^2 + (19.035)^2 \cdot (0.03)^2 \right]^{\frac{1}{2}}$$

$$W_h = (2.065 + 0.019 + .3260)^{\frac{1}{2}}$$

$$= \pm 2.09 \text{ W/m}^2 \text{ K}$$

$$\frac{W_h}{h} = \frac{2.09}{57.487} = \pm 3.64\%$$

For 3.0 W and component 3:

$$\frac{\partial h}{\partial Q_{net}} = \frac{1}{(5.76 \times 10^{-4})(38.38)} = 45.52$$

$$\frac{\partial h}{\partial A_{tot}} = \frac{3.0}{(5.76 \times 10^{-4})^2 (38.38)} = 235597.84$$

$$\frac{\partial h}{\partial \Delta T} = \frac{3.0}{\left(5.76 \times 10^{-4}\right)\left(38.38\right)^2} = 3,536$$

$$W_h = \left[\left(45.52\right)^2 \cdot \left(0.0742\right)^2 + \left(235597.8\right)^2 \cdot \left(1.41E-5\right)^2 + \left(3.54\right)^2 \cdot \left(.38\right)^2\right]^{\frac{1}{2}}$$

$$W_h = \pm 4.92 \ w/m^2 \ K$$

$$\frac{W_h}{h} = \frac{4.92}{135.7} = 3.63\%$$

To find the uncertainty of Nusselt Number:

$$Nu = \frac{h_L}{k}$$

$$Nu = f(h, \ L, \ k)$$

$$\frac{\partial Nu}{\partial h} = \frac{L}{k}$$

$$\frac{\partial Nu}{\partial L} = \frac{h}{k}$$

$$\frac{\partial Nu}{\partial k} = -\frac{hL}{k^2}$$

Since the thermal properties of the FC-75 (dielectric liquid) are values that depend on film temperatures, it is considered that there are no uncertainties in these values.

69

$$K = (0.65 - 7.89474E - 4 \cdot T_{film})/10$$

$$T_{film} = \frac{T_{avg} + T_{sink}}{2}$$

For 0.1 W and component 3:

$$K = 0.064 \frac{W}{m\,K}$$

$$T_{film} = 11.51° \text{ C}$$

$$\frac{\partial Nu}{\partial k} = \frac{24 \times 10^{-3} m}{0.064 \ w/m\,K} = 0.374$$

$$\frac{\partial Nu}{\partial k} = \frac{57.487}{24 \times 10^{-3}} = 2395.29$$

$$\frac{\partial Nu}{\partial k} = \frac{57.487 \times 24 \times 10^{-3}}{(0.064)^2} = 336.84$$

$$WNu = \left[\left(\frac{\partial Nu}{\partial h}\right)^2 Wh^2 + \left(\frac{\partial Nu}{\partial L}\right)^2 W_L^2 + \left(\frac{\partial Nu}{\partial k}\right)^2 Wk^2\right]^{\frac{1}{2}}$$

$$WNu = \left[(0.374)^2 \cdot (2.09)^2 + (2395.29)^2 \cdot (10^{-5})^2\right]^{\frac{1}{2}}$$

$$WNu = \pm 0.78$$

70

$$\frac{WNu}{Nu} = \frac{0.78}{21.55} = 0.036 = 3.6\%$$

For 3.0 W and component 3:

$$k_f = 0.0627 \frac{W}{mk}$$

$$T_{film} = 29.2° \text{ C}$$

$$\frac{\partial Nu}{\partial h} = \frac{24 \times 10^{-3} m}{0.0627} = 0.382$$

$$\frac{\partial Nu}{\partial L} = \frac{135.7}{24 \times 10^{-3}} = 5654.16$$

$$WNu = \left[(0.382)^2 \cdot (4.92)^2 + (5654.16)^2 \cdot (10^{-5})^2 \right]^{\frac{1}{2}}$$

$$WNu = \pm 1.88$$

$$\frac{WNu}{Nu} = \frac{1.88}{51.94} = 3.62\%$$

$$Ra_f = Gr_f \cdot Pr$$

$$Gr_f = \frac{g\beta L^4 Q_{net}}{k_f \nu^2 A_{tot}}$$

$$Pr = \frac{\nu}{\alpha}$$

$$Gr_f = f\left(g, \beta, L^4, Q_{net}, k_f, \nu^2, A_{tot}\right)$$

Consider fluid properties without uncertainties.

$$\frac{\partial Gr_f}{\partial L^4} = \frac{g\beta Q_{net}}{k_f \nu^2 A_{tot}}$$

$$\frac{\partial Gr_f}{\partial Q_{net}} = \frac{g\beta L^4}{k_f \nu^2 A_{tot}}$$

$$\frac{\partial Gr_f}{\partial A_{tot}} = \frac{g\beta L^4 Q_{net}}{k_f \nu^2 A_{tot}^2}$$

For 0.1 W and component 3:

$$\beta = 0.00137 \ K^{-1}$$

$$k_f = 0.064 \frac{W}{m.k}$$

$$\nu = 1.11259E-6 \frac{m^2}{s}$$

$$\frac{\partial Gr_f}{\partial L^4} = 2.94E13$$

72

$$\frac{\partial Gr_f}{\partial Q_{net}} = 9.76E7$$

$$\frac{\partial Gr_f}{\partial A_{tot}} = -1.69E10$$

$$WGr_f = \left[\left(\frac{\partial Gr_f}{\partial L^4}\right)^2 W^2 L^4 + \left(\frac{\partial Gr_f}{\partial Q_{net}}\right)^2 W^2 Q_{net} + \left(\frac{\partial Gr_f}{\partial A_{tot}}\right)^2 WA_{tot}\right]^{\frac{1}{2}}$$

$$WGr_f = \left[\begin{array}{l}(2.94E13)^2 \cdot (5.5\,E{-}10)^2 + (9.76E7)^2 \cdot (0.0025)^2 \\ + (1.69E10)^2 \cdot (4.8\,E{-}7)^2\end{array}\right]^{\frac{1}{2}}$$

$$WGr_f = [2.6E8 + 5.9536E10 + 6.5E7]^{\frac{1}{2}}$$

$$W_{Gr_f} = \pm 243569$$

$$\frac{W_{Gr_f}}{Gr_f} = \frac{243569}{9.67E6} = 2.5\%$$

$$W_{Ra_f} = 2.5\%$$

For 3.0 W and component 3:

$$\beta = 0.014\ K^{-1}$$

$$\nu = 0.80402 \times 10^{-6} \frac{m^2}{s}$$

$$k_f = 0.0627 \frac{W}{m.K}$$

$$\frac{\partial Gr_f}{\partial L^4} = 17.6E15$$

$$\frac{\partial Gr_f}{\partial Q_{net}} = 19.5E7$$

$$\frac{\partial Gr_f}{\partial A_{tot}} = 1.0E12$$

$$WGr_f = \left[(17.6E15)^2 \cdot (5.5E-10)^2 + (19.5E7)^2 \cdot (0.0742)^2 + (1.0E12)^2 \cdot (4.8E-7)^2 \right]^{\frac{1}{2}}$$

$$WGr_f = \left[9.3E13 + 2.09E14 + 2.38E11 \right]^{\frac{1}{2}}$$

$$\frac{WGr_f}{Gr_f} = \frac{17405183}{584920180} = 2.9\%$$

$$W_{Ra_f} = 2.9\%$$

APPENDIX C

TABLES

TABLE 1

TEMPERATURE DATA FOR INPUT POWER 0.1 W
BOTTOM BOUNDARY AT 20° C

RESULTS ARE STORED IN FILE: 08021455

AMBIENT TEMP : 24.3 C
VOLTMETER READING : 1.025 V
HEAT EXCHANGER TEMP.: 10-20 C

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1: POWER (WATTS):	17.46E+00 10.01E-02	17.49E+00	17.48E+00	17.47E+00	17.54E+00	18.04E+00
CHIP NO2: POWER (WATTS):	17.40E+00 10.00E-02	17.44E+00	17.47E+00	17.41E+00	17.47E+00	17.96E+00
CHIP NO3: POWER (WATTS):	17.13E+00 99.84E-03	17.08E+00	17.16E+00	17.22E+00	17.29E+00	17.61E+00
CHIP NO4: POWER (WATTS):	17.57E+00 98.84E-03	17.56E+00	17.44E+00	15.60E+00	17.48E+00	17.89E+00
CHIP NO5: POWER (WATTS):	17.48E+00 99.24E-03	17.62E+00	17.56E+00	17.51E+00	17.58E+00	17.92E+00
CHIP NO6: POWER (WATTS):	22.68E+00 99.12E-03	17.39E+00	17.43E+00	17.38E+00	17.55E+00	18.42E+00
IP NO7: POWER (WATTS):	17.59E+00 10.04E-02	17.62E+00	17.60E+00	17.55E+00	17.74E+00	18.32E+00
CHIP NO8: POWER (WATTS):	17.58E+00 10.07E-02	17.64E+00	17.67E+00	17.58E+00	17.60E+00	18.47E+00
CHIP NO9: POWER (WATTS):	17.33E+00 99.32E-03	17.15E+00	17.34E+00	17.30E+00	17.36E+00	17.82E+00

AVERAGE HEAT EXCHANGERS TEMPERATURES:
    BOTTOM: 10.01E+00
    TOP: 19.97E+00

BACK PLANE TEMPERATURES ARE :

    T(55): 17.81E+00
    T(56): 18.09E+00
    T(57): 17.54E+00
    T(72): 18.33E+00
    T(73): 18.43E+00
    T(74): 18.91E+00
    T(75): 18.07E+00
    T(76): 18.40E+00
    T(77): 18.29E+00

75

TABLE 2

TEMPERATURE DATA FOR INPUT POWER 0.7 W
BOTTOM BOUNDARY AT 20° C

RESULTS ARE STORED IN FILE: 08021717

AMBIENT TEMP : 24.4 C
VOLTMETER READING : 3.218 V
HEAT EXCHANGER TEMP.: 10-20 C

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	24.74E+00	24.02E+00	23.96E+00	24.00E+00	24.09E+00	27.01E+00
POWER (WATTS):	70.97E-02					
CHIP N02:	24.71E+00	23.81E+00	23.96E+00	23.54E+00	23.80E+00	26.56E+00
POWER (WATTS):	70.93E-02					
CHIP N03:	23.83E+00	23.69E+00	23.59E+00	23.55E+00	23.60E+00	25.11E+00
POWER (WATTS):	70.79E-02					
CHIP N04:	24.30E+00	23.71E+00	23.60E+00	20.65E+00	23.60E+00	25.74E+00
POWER (WATTS):	70.09E-02					
CHIP N05:	24.26E+00	23.46E+00	23.44E+00	23.37E+00	23.69E+00	25.46E+00
POWER (WATTS):	70.38E-02					
CHIP N06:	26.78E+00	24.05E+00	23.44E+00	23.51E+00	24.08E+00	27.57E+00
POWER (WATTS):	70.26E-02					
IP N07:	24.96E+00	24.47E+00	24.02E+00	23.81E+00	24.14E+00	27.58E+00
POWER (WATTS):	71.19E-02					
CHIP N08:	24.27E+00	24.14E+00	24.07E+00	23.85E+00	23.79E+00	29.43E+00
POWER (WATTS):	71.40E-02					
CHIP N09:	23.90E+00	23.70E+00	23.62E+00	23.50E+00	23.44E+00	26.70E+00
POWER (WATTS):	70.84E-02					

AVERAGE HEAT EXCHANGERS TEMPERATURES:
BOTTOM: 10.00E+00
TOP: 20.00E+00

BACK PLANE TEMPERATURES ARE :

T(55):   20.83E+00
T(56):   21.22E+00
T(57):   20.72E+00
T(72):   21.38E+00
T(73):   21.10E+00
T(74):   21.50E+00
T(75):   21.03E+00
T(76):   21.18E+00
T(77):   21.23E+00

76

TABLE 3

TEMPERATURE DATA FOR INPUT POWER 1.5 W
BOTTOM BOUNDARY AT 20° C

```
RESULTS ARE STORED IN FILE:  08030205

        AMBIENT TEMP :   24.4 C
        VOLTMETER READING :   4.7082 V
        HEAT EXCHANGER TEMP.:   10-20 C

    ALL TEMPERATURES ARE IN DEGREES CELCIUS
```

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1: POWER (WATTS):	33.28E+00 15.17E-01	31.29E+00	31.67E+00	31.63E+00	31.81E+00	37.53E+00
CHIP NO2: POWER (WATTS):	33.22E+00 15.16E-01	31.21E+00	31.50E+00	30.68E+00	31.25E+00	36.83E+00
CHIP NO3: POWER (WATTS):	31.23E+00 15.13E-01	31.26E+00	30.99E+00	30.76E+00	30.63E+00	34.16E+00
CHIP NO4: POWER (WATTS):	33.06E+00 14.98E-01	31.52E+00	31.54E+00	27.88E+00	31.60E+00	35.83E+00
CHIP NO5: POWER (WATTS):	32.56E+00 15.04E-01	30.25E+00	30.60E+00	30.44E+00	31.30E+00	34.65E+00
CHIP NO6: POWER (WATTS):	20.87E+00 15.01E-01	32.79E+00	30.75E+00	31.13E+00	32.43E+00	43.50E+00
CHIP NO7: POWER (WATTS):	33.79E+00 15.21E-01	32.54E+00	31.83E+00	31.29E+00	31.97E+00	38.83E+00
CHIP NO8: POWER (WATTS):	32.46E+00 15.26E-01	31.64E+00	31.72E+00	31.46E+00	31.25E+00	43.11E+00
CHIP NO9: POWER (WATTS):	31.47E+00 15.14E-01	31.25E+00	31.12E+00	30.80E+00	31.01E+00	37.41E+00

```
    AVERAGE HEAT EXCHANGERS TEMPERATURES:
        BOTTOM:                  10.09E+00
        TOP:                     20.04E+00

    BACK PLANE TEMPERATURES ARE :

        T(55):   23.97E+00
        T(56):   24.51E+00
        T(57):   25.06E+00
        T(72):   24.93E+00
        T(73):   24.57E+00
        T(74):   24.85E+00
        T(75):   25.10E+00
        T(76):   24.49E+00
        T(77):   24.61E+00
```

TABLE 4

TEMPERATURE DATA FOR INPUT POWER 3.0 W
BOTTOM BOUNDARY AT 20° C

RESULTS ARE STORED IN FILE: 08041705

AMBIENT TEMP :   24.5 C
VOLTMETER READING : 6.601 V
HEAT EXCHANGER TEMP.:   10-20 C

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	49.47E+00	45.65E+00	46.44E+00	46.13E+00	45.76E+00	56.26E+00
POWER (WATTS):	29.74E-01					
CHIP NO2:	48.99E+00	45.37E+00	46.33E+00	44.51E+00	46.02E+00	56.02E+00
POWER (WATTS):	29.73E-01					
CHIP NO3:	44.62E+00	45.57E+00	45.04E+00	44.58E+00	44.60E+00	51.20E+00
POWER (WATTS):	29.68E-01					
CHIP NO4:	49.59E+00	46.17E+00	46.77E+00	42.62E+00	46.97E+00	54.89E+00
POWER (WATTS):	29.38E-01					
CHIP NO5:	48.69E+00	43.92E+00	45.19E+00	44.75E+00	46.43E+00	52.53E+00
POWER (WATTS):	29.51E-01					
CHIP NO6:	37.80E+00	48.64E+00	45.04E+00	45.78E+00	47.85E+00	68.62E+00
POWER (WATTS):	29.40E-01					
CHIP NO7:	51.18E+00	48.27E+00	47.48E+00	46.51E+00	47.28E+00	58.60E+00
POWER (WATTS):	29.82E-01					
CHIP NO8:	48.09E+00	47.05E+00	47.09E+00	46.58E+00	45.99E+00	67.94E+00
POWER (WATTS):	29.91E-01					
CHIP NO9:	44.97E+00	45.78E+00	45.57E+00	45.11E+00	44.78E+00	58.25E+00
POWER (WATTS):	29.69E-01					

AVERAGE HEAT EXCHANGERS TEMPERATURES:
BOTTOM: 10.98E+00
TOP: 20.08E+00

BACK PLANE TEMPERATURES ARE :

T(55):   31.46E+00
T(56):   32.62E+00
T(57):   34.30E+00
T(72):   33.38E+00
T(73):   32.78E+00
T(74):   33.27E+00
T(75):   33.99E+00
T(76):   32.43E+00
T(77):   32.42E+00

78

TABLE 5

REDUCED DATA FOR INPUT POWER 0.1 W
BOTTOM BOUNDARY AT 20° C

```
            THE RAW Emf DATA ARE FROM THE FILE:   08021455
            THE POWER SETTING PER CHIP WAS:   0.1 W
```

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	99.93E-03	74.63E-01	29.10E-01	13.42E-01

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 139.72E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :134.16E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 406.58E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 458.54E-05

| 2 | 99.84E-03 | 74.15E-01 | 29.26E-01 | 13.50E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 138.74E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :135.03E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 405.97E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 458.97E-05

| 3 | 99.64E-03 | 71.59E-01 | 30.24E-01 | 13.99E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 133.57E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :139.86E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 403.97E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 459.86E-05

| 4 | 98.64E-03 | 70.22E-01 | 30.52E-01 | 14.26E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 130.83E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :142.58E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 399.28E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 464.52E-05

| 5 | 99.04c-03 | 75.15E-01 | 28.64E-01 | 13.32E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 140.78E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :133.23E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 403.22E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 462.64E-05

| 6 | 98.92E-03 | 91.61E-01 | 23.49E-01 | 10.93E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 174.75E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :109.29E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 410.50E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 463.23E-05

| 7 | 10.02E-02 | 75.85E-01 | 28.72E-01 | 13.20E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 142.19E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :132.01E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 408.40E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 457.14E-05

| 8 | 10.05E-02 | 75.98E-01 | 28.75E-01 | 13.18E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 142.45E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :131.78E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 409.59E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 455.89E-05

| 9 | 99.72E-03 | 73.00E-01 | 29.68E-01 | 13.72E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 136.42E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :137.15E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 404.94E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 459.52E-05

TABLE 6

REDUCED DATA FOR INPUT POWER 0.7 W
BOTTOM BOUNDARY AT 20° C

THE RAW Emf DATA ARE FROM THE FILE: 08021717
THE POWER SETTING PER CHIP WAS: 0.7 WATTS

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	70.20E-02	14.24E+00	10.76E+00	70.34E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 297.08E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :703.04E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 308.85E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 231.59E-04

| 2 | 70.16E-02 | 14.08E+00 | 10.88E+00 | 71.16E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 283.28E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :711.21E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 308.10E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 231.71E-04

| 3 | 70.03E-02 | 13.66E+00 | 11.18E+00 | 73.32E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 273.69E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :732.84E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 306.03E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 232.17E-04

| 4 | 69.32E-02 | 13.10E+00 | 11.54E+00 | 76.47E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 260.80E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :764.36E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 301.00E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 234.54E-04

| 5 | 69.61E-02 | 13.71E+00 | 11.08E+00 | 73.06E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 274.81E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :730.23E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 304.37E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 233.57E-04

| 6 | 69.49E-02 | 14.67E+00 | 10.34E+00 | 68.30E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 297.03E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :682.63E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 307.22E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 233.95E-04

| 7 | 70.42E-02 | 14.32E+00 | 10.73E+00 | 69.95E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 288.95E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :699.10E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 310.07E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 230.88E-04

| 8 | 70.63E-02 | 14.06E+00 | 10.96E+00 | 71.25E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 282.84E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :712.17E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 310.07E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 230.19E-04

| 9 | 70.07E-02 | 13.67E+00 | 11.18E+00 | 73.27E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 273.90E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :732.34E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 306.28E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 232.01E-04

80

TABLE 7

REDUCED DATA FOR INPUT POWER 1.5 W
BOTTOM BOUNDARY AT 20° C

THE RAW Emf DATA ARE FROM THE FILE: 08030205
THE POWER SETTING PER CHIP WAS: 1.5 WATTS

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	15.00E-01	22.08E+00	14.90E+00	45.39E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 484.85E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :453.37E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 722.22E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.19E-04

| 2 | 14.99E-01 | 21.73E+00 | 15.13E+00 | 46.13E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 475.36E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :460.71E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 719.11E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.28E-04

| 3 | 14.96E-01 | 20.92E+00 | 15.68E+00 | 47.92E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 453.60E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :478.68E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 711.25E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.71E-04

| 4 | 14.81E-01 | 21.04E+00 | 15.43E+00 | 47.63E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 457.00E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :475.76E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 705.05E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 228.02E-04

| 5 | 14.87E-01 | 21.15E+00 | 15.42E+00 | 47.39E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 459.81E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :473.39E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 708.81E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.07E-04

| 6 | 14.84E-01 | 17.77E+00 | 18.26E+00 | 56.38E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 372.79E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :563.37E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 680.72E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.65E-04

| 7 | 15.04E-01 | 22.33E+00 | 14.78E+00 | 44.90E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 491.49E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :448.39E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 726.23E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 224.56E-04

| 8 | 15.09E-01 | 21.76E+00 | 15.20E+00 | 46.06E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 476.17E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :460.08E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 723.92E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 223.86E-04

| 9 | 14.97E-01 | 21.07E+00 | 15.58E+00 | 47.58E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 457.63E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :475.23E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 712.92E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.59E-04

TABLE 8

REDUCED DATA FOR INPUT POWER 3.0 W
BOTTOM BOUNDARY AT 20° C

THE RAW Emf DATA ARE FROM THE FILE: 08041705
THE POWER SETTING PER CHIP WAS: 3.0 WATTS

.H.P	QNET(W)	Tavg-Ts	Nu	%UNC IM Nu
1	29.42E-01	36.28E+00	17.97E+00	27.67E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 936.63E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :276.00E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 168.28E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 194.60E-04

| 2 | 29.41E-01 | 35.68E+00 | 18.25E+00 | 28.13E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 915.94E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :280.60E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 167.20E-02
% UMCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 194.65E-04

| 3 | 29.36E-01 | 33.82E+00 | 19.20E+00 | 29.67E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 852.28E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :296.05E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 163.66E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 195.00E-04

| 4 | 29.06E-01 | 35.66E+00 | 18.05E+00 | 28.14E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 915.27E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :280.75E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 165.19E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 196.99E-04

| 5 | 29.19E-01 | 35.27E+00 | 18.32E+00 | 28.46E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 901.62E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :283.89E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 165.19E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 196.17E-04

| 6 | 29.08E-01 | 32.37E+00 | 19.85E+00 | 30.99E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 804.05E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :309.31E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 159.62E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 196.89E-04

| 7 | 29.50E-01 | 37.54E+00 | 17.42E+00 | 26.74E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 981.44E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :266.69E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 170.99E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 194.07E-04

| 8 | 29.59E-01 | 36.23E+00 | 18.09E+00 | 27.71E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 934.88E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :276.38E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 169.15E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 193.51E-04

| 9 | 29.37E-01 | 34.23E+00 | 18.98E+00 | 29.32E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 866.10E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :292.51E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 164.42E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 194.95E-04

TABLE 9

TEMPERATURE DATA FOR INPUT POWER 0.1 W
BOTTOM BOUNDARY INSULATED

THESE RESULTS ARE STORED IN FILE: 08221255

AMBIENT TEMP WAS: 23.0 C
VOLTMETER READING WAS: 1.2134 V
BATH TEMP WAS: 10 C-INSUL

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	15.92E+00	15.85E+00	15.85E+00	15.82E+00	15.87E+00	16.36E+00
POWER (WATTS):	10.08E-02					
CHIP NO2:	15.92E+00	15.95E+00	15.98E+00	15.87E+00	15.95E+00	16.44E+00
POWER (WATTS):	10.07E-02					
CHIP NO3:	15.71E+00	15.66E+00	15.76E+00	15.82E+00	15.86E+00	16.14E+00
POWER (WATTS):	10.05E-02					
CHIP NO4:	15.77E+00	15.93E+00	15.72E+00	15.64E+00	15.71E+00	16.12E+00
POWER (WATTS):	99.49E-03					
CHIP NO5:	15.77E+00	15.87E+00	15.84E+00	15.77E+00	15.85E+00	16.20E+00
POWER (WATTS):	99.89E-03					
CHIP NO6:	17.93E+00	15.73E+00	15.77E+00	15.71E+00	12.78E+00	16.53E+00
POWER (WATTS):	99.74E-03					
CHIP NO7:	15.75E+00	15.79E+00	15.75E+00	15.71E+00	15.84E+00	16.41E+00
POWER (WATTS):	10.11E-02					
CHIP NO8:	15.85E+00	15.36E+00	15.91E+00	15.82E+00	15.83E+00	16.56E+00
POWER (WATTS):	10.14E-02					
CHIP NO9:	15.56E+00	15.49E+00	15.62E+00	15.59E+00	15.64E+00	16.15E+00
POWER (WATTS):	10.05E-02					

HEAT EXCHANGERS TEMPERATURES: RIGHT   LEFT
   BOTTOM: 15.97E+00 15.97E+00
   TOP: 10.20E+00 96.30E-01

BACK PLANE TEMPERATURES ARE :

```
T(55):  16.01E+00
T(56):  16.41E+00
T(57):  16.01E+00
T(72):  16.73E+00
T(73):  16.78E+00
T(74):  17.24E+00
T(75):  16.42E+00
T(76):  16.75E+00
T(77):  16.69E+00
```

83

TABLE 10

TEMPERATURE DATA FOR INPUT POWER 0.7 W
BOTTOM BOUNDARY INSULATED

THESE RESULTS ARE STORED IN FILE: 08222257

AMBIENT TEMP WAS: 21.7 C
VOLTMETER READING WAS: 3.22 V
BATH TEMP WAS: 10 C-INS

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	23.67E+00	22.36E+00	22.84E+00	22.84E+00	22.85E+00	25.39E+00
POWER (WATTS):	70.88E-02					
CHIP NO2:	23.52E+00	22.57E+00	22.76E+00	22.30E+00	22.68E+00	25.39E+00
POWER (WATTS):	70.83E-02					
CHIP NO3:	22.90E+00	22.62E+00	22.51E+00	22.47E+00	22.24E+00	24.00E+00
POWER (WATTS):	70.63E-02					
CHIP NO4:	23.46E+00	22.91E+00	22.73E+00	22.17E+00	22.67E+00	24.75E+00
POWER (WATTS):	69.99E-02					
CHIP NO5:	23.20E+00	22.20E+00	22.27E+00	22.14E+00	22.60E+00	24.21E+00
POWER (WATTS):	70.28E-02					
CHIP NO6:	26.26E+00	22.78E+00	22.23E+00	22.30E+00	18.88E+00	26.38E+00
POWER (WATTS):	70.15E-02					
C TP NO7:	23.85E+00	23.15E+00	22.80E+00	22.60E+00	22.93E+00	25.70E+00
POWER (WATTS):	71.09E-02					
CHIP NO8:	23.17E+00	22.97E+00	22.85E+00	22.70E+00	22.60E+00	26.66E+00
POWER (WATTS):	71.30E-02					
CHIP NO9:	22.70E+00	22.48E+00	22.43E+00	22.26E+00	22.24E+00	25.53E+00
POWER (WATTS):	70.72E-02					

HEAT EXCHANGERS TEMPERATURES: RIGHT   LEFT
    BOTTOM: 17.35E+00 17.36E+00
    TOP: 10.29E+00 97.63E-01

BACK PLANE TEMPERATURES ARE :

T(55): 19.34E+00
T(56): 19.81E+00
T(57): 19.74E+00
T(72): 20.01E+00
T(73): 71.30E-01
T(74): 19.99E+00
T(75): 19.59E+00
T(76): 19.76E+00
T(77): 19.88E+00

TABLE 11

TEMPERATURE DATA FOR INPUT POWER 1.1 W
BOTTOM BOUNDARY INSULATED

THESE RESULTS ARE STORED IN FILE: 08231010

AMBIENT TEMP WAS: 21.33 C
VOLTMETER READING WAS: 4.00 V
BATH TEMP WAS: 10 C-INS

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	28.35E+00	26.73E+00	27.12E+00	27.11E+00	27.13E+00	30.82E+00
POWER (WATTS):	10.96E-01					
CHIP NO2:	28.16E+00	26.70E+00	26.93E+00	26.29E+00	26.90E+00	30.97E+00
POWER (WATTS):	10.95E-01					
CHIP NO3:	26.96E+00	26.97E+00	26.70E+00	26.57E+00	26.26E+00	28.94E+00
POWER (WATTS):	10.93E-01					
CHIP NO4:	28.21E+00	27.02E+00	27.14E+00	26.29E+00	27.07E+00	30.17E+00
POWER (WATTS):	10.82E-01					
CHIP NO5:	27.75E+00	26.13E+00	26.25E+00	26.09E+00	26.86E+00	29.20E+00
POWER (WATTS):	10.87E-01					
CHIP NO6:	27.17E+00	27.20E+00	26.33E+00	26.45E+00	25.80E+00	32.61E+00
POWER (WATTS):	10.84E-01					
CHIP NO7:	28.65E+00	27.60E+00	27.07E+00	26.77E+00	27.15E+00	31.29E+00
POWER (WATTS):	10.99E-01					
CHIP NO8:	27.65E+00	26.99E+00	27.08E+00	26.92E+00	26.57E+00	32.87E+00
POWER (WATTS):	11.02E-01					
CHIP NO9:	26.81E+00	26.65E+00	26.59E+00	26.36E+00	26.23E+00	31.29E+00
POWER (WATTS):	10.93E-01					

HEAT EXCHANGERS TEMPERATURES: RIGHT   LEFT
    BOTTOM: 18.43E+00 18.43E+00
    TOP: 10.21E+00 97.25E-01 ⚡

BACK PLANE TEMPERATURES ARE :

T(55):   21.49E+00
T(56):   22.00E+00
T(57):   22.27E+00
T(72):   22.32E+00
T(73):   21.94E+00
T(74):   22.22E+00
T(75):   22.04E+00
T(76):   21.97E+00
T(77):   22.12E+00

TABLE 12

TEMPERATURE DATA FOR INPUT POWER 3.0 W
BOTTOM BOUNDARY INSULATED

THESE RESULTS ARE STORED IN FILE: 08231310

AMBIENT TEMP WAS: 23 C
VOLTMETER READING WAS: 4.00 V
BATH TEMP WAS: 10 C-INS

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	54.28E+00	49.66E+00	50.72E+00	50.63E+00	50.34E+00	59.54E+00
POWER (WATTS):	30.12E-01					
CHIP N02:	53.84E+00	49.73E+00	50.52E+00	48.65E+00	50.06E+00	60.06E+00
POWER (WATTS):	30.11E-01					
CHIP N03:	50.25E+00	50.25E+00	49.56E+00	49.03E+00	47.98E+00	55.22E+00
POWER (WATTS):	30.06E-01					
CHIP N04:	53.66E+00	49.90E+00	50.54E+00	48.37E+00	50.35E+00	58.19E+00
POWER (WATTS):	29.77E-01					
CHIP N05:	52.76E+00	47.84E+00	48.71E+00	48.29E+00	49.81E+00	55.75E+00
POWER (WATTS):	29.89E-01					
CHIP N06:	55.76E+00	51.99E+00	48.65E+00	49.14E+00	50.78E+00	70.28E+00
POWER (WATTS):	29.78E-01					
C P N07:	55.44E+00	51.67E+00	50.76E+00	50.15E+00	50.57E+00	60.78E+00
POWER (WATTS):	30.21E-01					
CHIP N08:	52.46E+00	51.07E+00	51.00E+00	50.88E+00	50.31E+00	67.37E+00
POWER (WATTS):	30.30E-01					
CHIP N09:	50.77E+00	50.34E+00	49.91E+00	49.40E+00	49.60E+00	61.43E+00
POWER (WATTS):	30.06E-01					

HEAT EXCHANGERS TEMPERATURES: RIGHT   LEFT
BOTTOM: 21.94E+00   21.96E+00
TOP: 11.02E+00   98.81E-01

BACK PLANE TEMPERATURES ARE :

T(55):   32.74E+00
T(56):   34.26E+00
T(57):   36.45E+00
T(72):   35.41E+00
T(73):   34.75E+00
T(74):   35.18E+00
T(75):   35.96E+00
T(76):   34.28E+00
T(77):   34.30E+00

86

TABLE 13

REDUCED DATA FOR INPUT POWER 0.1 W
BOTTOM BOUNDARY INSULATED

THE RAW Emf DATA ARE FROM THE FILE: 08221255
THE POWER SETTING PER CHIP WAS: 0.1 WATTS

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	10.06E-02	59.19E-01	35.91E-01	16.93E-01

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 108.69E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :169.28E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 401.14E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 394.13E-05

| 2 | 10.05E-02 | 60.09E-01 | 36.31E-01 | 16.67E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 110.46E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :166.74E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 401.11E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 394.58E-05

| 3 | 10.03E-02 | 53.46E-01 | 37.24E-01 | 17.14E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 107.28E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :171.38E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 399.54E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 395.38E-05

| 4 | 99.33E-03 | 53.11E-01 | 37.11E-01 | 17.24E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 106.58E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :172.43E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 395.51E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 399.24E-05

| 5 | 99.73E-03 | 58.84E-01 | 36.79E-01 | 17.03E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 108.02E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :170.27E-02
FLUX BASED RAYLEIGH NUMBER + E-8 IS: 397.44E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 397.65E-05

| 6 | 99.58E-03 | 53.05E-01 | 34.29E-01 | 15.89E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 116.29E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :158.90E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 398.81E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 398.24E-05

| 7 | 10.09E-02 | 58.34E-01 | 37.56E-01 | 17.17E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 107.04E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :171.73E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 402.00E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 392.90E-05

| 8 | 10.12E-02 | 59.41E-01 | 36.98E-01 | 16.87E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 109.12E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :168.66E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 403.56E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 391.87E-05

| 9 | 10.04E-02 | 56.68E-01 | 38.43E-01 | 17.68E-01 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 103.80E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :176.77E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 398.95E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 395.13E-05

TABLE 14

REDUCED DATA FOR INPUT POWER 0.7 W
BOTTOM BOUNDARY INSULATED

THE RAW Emf DATA ARE FROM THE FILE: 08222257
THE POWER SETTING PER CHIP WAS: 0.7 WATTS

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	70.13E-02	13.10E+00	11.67E+00	76.47E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 261.03E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :764.35E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 304.66E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 234.56E-04

| 2 | 70.07E-02 | 12.85E+00 | 11.89E+00 | 77.95E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 255.36E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :779.20E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 303.54E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 234.75E-04

| 3 | 69.94E-02 | 12.59E+00 | 12.11E+00 | 79.57E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 249.47E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :795.34E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 302.04E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 235.21E-04

| 4 | 69.24E-02 | 12.82E+00 | 11.78E+00 | 78.16E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 254.59E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :781.28E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 299.83E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 237.56E-04

| 5 | 69.53E-02 | 12.54E+00 | 12.08E+00 | 79.88E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 248.36E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :798.47E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 300.13E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 236.58E-04

| 6 | 69.40E-02 | 13.34E+00 | 11.35E+00 | 75.14E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 266.31E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :751.07E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 302.30E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 237.02E-04

| 7 | 70.34E-02 | 13.12E+00 | 11.70E+00 | 76.40E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 261.31E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :763.62E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 305.62E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 233.86E-04

| 8 | 70.55E-02 | 12.88E+00 | 11.95E+00 | 77.82E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 255.86E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :777.86E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 305.69E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 233.16E-04

| 9 | 69.97E-02 | 12.44E+00 | 12.26E+00 | 80.54E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 246.04E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :805.10E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 301.64E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 235.11E-04

TABLE 15

REDUCED DATA FOR INPUT POWER 1.1 W
BOTTOM BOUNDARY INSULATED

```
            THE RAW Emf DATA ARE FROM THE FILE:   08231010
            THE POWER SETTING PER CHIP WAS:   1.1 WATTS
```

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	10.84E-01	17.53E+00	13.52E+00	57.17E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 365.80E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :571.25E-03
FLUX BASED RAYLEIGH NUMBER * E-9 IS: 494.53E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 226.98E-04

| 2 | 10.83E-01 | 17.19E+00 | 13.77E+00 | 58.29E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 357.49E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :582.43E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 492.30E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.14E-04

| 3 | 10.81E-01 | 16.77E+00 | 14.09E+00 | 59.75E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 347.17E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :597.04E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 489.01E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.58E-04

| 4 | 10.70E-01 | 17.30E+00 | 13.52E+00 | 57.93E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 360.14E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :578.80E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 487.09E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 229.85E-04

| 5 | 10.75E-01 | 16.78E+00 | 14.00E+00 | 59.71E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 347.42E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :596.67E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 486.30E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 228.88E-04

| 6 | 10.73E-01 | 16.70E+00 | 14.03E+00 | 60.00E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 345.45E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :599.56E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 484.82E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 229.37E-04

| 7 | 10.87E-01 | 17.61E+00 | 13.50E+00 | 56.91E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 367.76E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :568.68E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 496.47E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 226.30E-04

| 8 | 10.90E-01 | 17.22E+00 | 13.85E+00 | 58.21E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 358.03E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :581.69E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 495.81E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.59E-04

| 9 | 10.81E-01 | 16.61E+00 | 14.23E+00 | 60.32E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 348.28E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :602.77E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 488.34E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.49E-04

89

TABLE 16

REDUCED DATA FOR INPUT POWER 3.0 W
BOTTOM BOUNDARY INSULATED

THE RAW Emf DATA ARE FROM THE FILE: 08231310
THE POWER SETTING PER CHIP WAS: 3.0 WATTS

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	29.78E-01	41.31E+00	16.01E+00	24.31E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 110.90E-02
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :242.30E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 177.54E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 202.57E-04

| 2 | 29.77E-01 | 40.60E+00 | 16.28E+00 | 24.74E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 108.25E-02
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :246.54E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 176.18E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 202.65E-04

| 3 | 29.72E-01 | 39.13E+00 | 16.84E+00 | 25.66E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 102.84E-02
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :255.82E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 173.21E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 203.01E-04

| 4 | 29.42E-01 | 40.51E+00 | 16.12E+00 | 24.79E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 107.92E-02
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :247.08E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 173.98E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 205.02E-04

| 5 | 29.55E-01 | 39.52E+00 | 16.59E+00 | 25.41E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 104.27E-02
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :253.28E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 172.94E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 204.15E-04

| 6 | 29.44E-01 | 41.15E+00 | 15.99E+00 | 24.42E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 110.27E-02
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :243.29E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 175.19E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 204.93E-04

| 7 | 29.87E-01 | 41.77E+00 | 15.89E+00 | 24.05E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 112.63E-02
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :239.64E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 178.94E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 201.94E-04

| 8 | 29.96E-01 | 40.95E+00 | 16.25E+00 | 24.53E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 109.55E-02
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :244.43E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 177.96E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 201.34E-04

| 9 | 29.72E-01 | 39.63E+00 | 16.64E+00 | 25.34E-02 |

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 104.65E-02
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :252.60E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 174.11E-02
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 203.00E-04

TABLE 17

TEMPERATURE DATA FOR INPUT POWER 0.1 W
CHAMBER WIDTH = 30 mm

```
RESULTS ARE STORED IN FILE: 10161810

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF:    24.33
BATH TEMP :   10 C-10 C
TEMPERATURE READINGS IN DEGREES CELSIUS
            CENTER    TOP    RIGHT   LEFT    BOTTOM    BACK
CHIP NO1: 12.806   12.761   12.736  12.771  12.616   15.431
   POWER (WATTS):    .0983
CHIP NO2: 12.954   12.894   12.591  12.861  12.816   15.438
   POWER (WATTS):    .099
CHIP NO3: 13.099   12.956   00.000  12.906  13.076   15.451
   POWER (WATTS):    .0996
CHIP NO4: 12.764   12.731   12.536  12.574  12.484   15.441
   POWER (WATTS):    .0990
CHIP NO5: 12.831   12.894   12.836  12.824  12.801   15.446
   POWER (WATTS):    .0993
CHIP NO6: 13.019   12.914   12.979  11.858  12.746   15.448
   POWER (WATTS):    .0995
CHIP NO7: 12.689   12.686   12.706  12.684  12.559   15.445
   POWER (WATTS):    .0992
CHIP NO8: 13.039   12.941   12.966  00.000  12.901   15.442
   POWER (WATTS):    .0990
CHIP NO9: 13.256   13.114   12.834  13.144  13.144   15.445
   POWER (WATTS):    .0992

HEAT EXCHANGERS TEMPERATURES:       RIGHT   CENTER   LEFT
       BOTTOM:                      09.967  10.012   09.997
       TOP:                         10.037  00.000   10.042

BACK PLANE TEMPERATURES :
T(55):   12.656
T(56):   12.961
T(57):   12.709
T(74):   13.131
T(75):   13.561
T(76):   13.671
T(77):   13.366

SOURCE VOLTAGE:  1.225

VOLTAGE TO THE HEATERS :
CHIP #1:    .972
CHIP #2:   1.027
CHIP #3:   1.022
CHIP #4:   1.024
CHIP #5:    .968
CHIP #6:   1.022
CHIP #7:   1.023
CHIP #8:   1.023
CHIP #9:   1.023
```

TABLE 18

TEMPERATURE DATA FOR INPUT POWER 0.7 W
CHAMBER WIDTH = 30 mm

```
RESULTS ARE STORED IN FILE:  10170950

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF:     24.78
BATH TEMP  :   10 C-10 C
TEMPERATURE READINGS IN DEGREES CELSIUS
            CENTER    TOP    RIGHT    LEFT    BOTTOM    BACK
CHIP NO1: 21.48    21.22    21.08    21.31    20.01     24.28
   POWER (WATTS):    .708
CHIP NO2: 22.18    21.50    18.45    21.41    20.88     24.34
   POWER (WATTS):    .712
CHIP NO3: 22.65    21.48    00.00    21.56    21.98     24.44
   POWER (WATTS):    .719
CHIP NO4: 21.68    21.26    20.78    21.12    20.37     24.39
   POWER (WATTS):    .715
CHIP NO5: 21.93    21.19    21.53    21.74    21.48     24.42
   POWER (WATTS):    .718
CHIP NO6: 22.75    21.81    22.07    20.73    20.12     24.48
   POWER (WATTS):    .721
CHIP NO7: 21.14    20.83    21.34    20.95    19.34     24.44
   POWER (WATTS):    .719
CHIP NO8: 22.00    21.42    21.32    00.00    20.87     24.43
   POWER (WATTS):    .718
CHIP NO9: 22.65    20.64    18.15    22.02    21.83     24.42
   POWER (WATTS):    .717

HEAT EXCHANGERS TEMPERATURES:      RIGHT    CENTER    LEFT
          BOTTOM:                  09.922   10.017   09.972
          TOP:                     09.977   00.000   10.060

BACK PLANE TEMPERATURES  :
T(55):   15.191
T(56):   15.611
T(57):   14.265
T(74):   15.651
T(75):   16.079
T(76):   16.521
T(77):   15.350

SOURCE VOLTAGE:  3.288

VOLTAGE TO THE HEATERS :
CHIP #1:    2.610
CHIP #2:    2.756
CHIP #3:    2.743
CHIP #4:    2.747
CHIP #5:    2.597
CHIP #6:    2.741
CHIP #7:    2.743
CHIP #8:    2.744
CHIP #9:    2.745
```

TABLE 19

TEMPERATURE DATA FOR INPUT POWER 1.1 W
CHAMBER WIDTH = 30 mm

```
RESULTS ARE STORED IN FILE:  10171720

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF:      25.94
BATH TEMP  :   10 C-10 C
TEMPERATURE READINGS IN DEGREES CELSIUS
          CENTER    TOP    RIGHT    LEFT    BOTTOM    BACK
CHIP NO1: 26.38    25.79   25.94   26.17   24.21    29.857
  POWER (WATTS):   1.092
CHIP NO2: 27.34    26.00   22.01   26.17   25.62    29.96
  POWER (WATTS):   1.099
CHIP NO3: 27.67    25.73   00.00   26.08   26.69    30.11
  POWER (WATTS):   1.1093
CHIP NO4: 26.74    26.07   25.51   26.00   24.85    30.02
  POWER (WATTS):   1.103
CHIP NO5: 29.78    25.86   26.40   26.71   26.35    30.08
  POWER (WATTS):   1.107
CHIP NO6: 27.51    25.54   26.74   25.65   24.17    30.16
  POWER (WATTS):   1.113
CHIP NO7: 25.80    25.40   26.18   25.63   22.98    30.10
  POWER (WATTS):   1.109
CHIP NO8: 27.06    25.80   26.15   00.00   25.29    30.11
  POWER (WATTS):   1.109
CHIP NO9: 27.79    24.71   21.36   26.94   26.60    30.11
  POWER (WATTS):   1.110

HEAT EXCHANGERS TEMPERATURES:       RIGHT    CENTER    LEFT
  BOTTOM:                          09.924    10.015   09.987
  TOP:                             10.010    00.000   10.068

BACK PLANE TEMPERATURES  :
  T(55):   16.88
  T(56):   17.48
  T(57):   15.70
  T(74):   17.57
  T(75):   18.00
  T(76):   18.49
  T(77):   17.08

SOURCE VOLTAGE:  4.085

VOLTAGE TO THE HEATERS :
  CHIP #1:    3.244
  CHIP #2:    3.424
  CHIP #3:    3.408
  CHIP #4:    3.413
  CHIP #5:    3.228
  CHIP #6:    3.406
  CHIP #7:    3.408
  CHIP #8:    3.408
  CHIP #9:    3.408
```

TABLE 20

TEMPERATURE DATA FOR INPUT POWER 1.5 W
CHAMBER WIDTH = 30 mm

RESULTS ARE STORED IN FILE: 10181020

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 23.94
BATH TEMP :   10 C-10 C
TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	33.07	32.50	32.62	32.72	29.91	35.55
POWER (WATTS):	1.484					
CHIP NO2:	34.32	32.62	27.17	32.75	31.80	35.68
POWER (WATTS):	1.493					
CHIP NO3:	34.63	32.10	00.00	32.62	33.39	35.89
POWER (WATTS):	1.5077					
CHIP NO4:	33.56	32.40	31.90	32.49	30.83	35.79
POWER (WATTS):	1.501					
CHIP NO5:	33.39	32.19	32.67	33.16	32.64	35.87
POWER (WATTS):	1.506					
CHIP NO6:	34.02	31.20	33.07	32.41	29.59	35.97
POWER (WATTS):	1.513					
CHIP NO7:	32.02	30.79	32.47	31.73	27.98	35.89
POWER (WATTS):	1.508					
CHIP NO8:	33.89	32.28	32.71	00.00	31.39	35.89
POWER (WATTS):	1.507					
CHIP NO9:	34.69	31.22	26.04	33.41	33.00	35.88
POWER (WATTS):	1.507					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	10.027	10.098	10.073
TOP:	10.108	00.000	10.126

BACK PLANE TEMPERATURES :
T(55):   19.59
T(56):   20.25
T(57):   17.80
T(74):   21.09
T(75):   20.76
T(76):   21.47
T(77):   19.69

SOURCE VOLTAGE: 4.767

VOLTAGE TO THE HEATERS :
CHIP #1:   3.787
CHIP #2:   3.997
CHIP #3:   3.979
CHIP #4:   3.983
CHIP #5:   3.767
CHIP #6:   3.975
CHIP #7:   3.979
CHIP #8:   3.979
CHIP #9:   3.979
           THESE RESULTS ARE NOW STORED ON DISK 'FASTSCAN

FILE: 30MM10R

94

TABLE 21

TEMPERATURE DATA FOR INPUT POWER 2.5 W
CHAMBER WIDTH = 30 mm

```
RESULTS ARE STORED IN FILE: 10182338

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF:      23.17
BATH TEMP  :   10 C
TEMPERATURE READINGS IN DEGREES CELSIUS
          CENTER    TOP    RIGHT    LEFT   BOTTOM    BACK
CHIP NO1: 42.47   41.80   41.39    42.04   37.20    49.73
  POWER (WATTS):   2.461
CHIP NO2: 44.31   40.93   41.68    41.68   40.14    49.93
  POWER (WATTS):   2.475
CHIP NO3: 44.77   41.10   00.00    41.43   42.66    50.28
  POWER (WATTS):   2.4985
CHIP NO4: 42.78   40.79   40.47    41.00   38.73    50.08
  POWER (WATTS):   2.485
CHIP NO5: 42.58   42.08   41.60    42.36   41.83    50.20
  POWER (WATTS):   2.494
CHIP NO6: 42.77   38.65   41.30    41.37   35.79    50.41
  POWER (WATTS):   2.507
CHIP NO7: 40.63   39.59   41.08    40.51   34.17    50.25
  POWER (WATTS):   2.497
CHIP NO8: 42.02   39.95   40.79    00.00   37.88    50.27
  POWER (WATTS):   2.498
CHIP NO9: 42.77   37.10   41.32    41.32   40.60    50.24
  POWER (WATTS):   2.496

HEAT EXCHANGERS TEMPERATURES:      RIGHT   CENTER    LEFT
   BOTTOM:                         10.020  10.110   10.065
   TOP:                            09.748  00.000   10.015

BACK PLANE TEMPERATURES  :
T(55):   21.28
T(56):   22.30
T(57):   19.47
T(74):   23.34
T(75):   22.77
T(76):   23.81
T(77):   21.70

SOURCE VOLTAGE:  6.142

VOLTAGE TO THE HEATERS :
CHIP #1:   4.881
CHIP #2:   5.152
CHIP #3:   5.128
CHIP #4:   5.135
CHIP #5:   4.859
CHIP #6:   5.124
CHIP #7:   5.129
CHIP #8:   5.129
CHIP #9:   5.129
```

TABLE 22

TEMPERATURE DATA FOR INPUT POWER 3.0 W
CHAMBER WIDTH = 30 mm

```
RESULTS ARE STORED IN FILE:  10232224

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF:   22.83
BATH TEMP  :   10 C
TEMPERATURE READINGS IN DEGREES CELSIUS
            CENTER    TOP    RIGHT   LEFT   BOTTOM   BACK
CHIP NO1: 50.66   49.62   49.07   49.97   43.61   57.87
   POWER (WATTS):   3.022
CHIP NO2: 52.71   47.72   49.42   49.42   46.37   58.10
   POWER (WATTS):   3.038
CHIP NO3: 52.51   48.65   00.00   47.22   49.87   58.53
   POWER (WATTS):   3.0672
CHIP NO4: 51.15   47.96   48.59   48.79   46.00   58.30
   POWER (WATTS):   3.051
CHIP NO5: 50.48   48.36   49.36   50.54   48.61   58.47
   POWER (WATTS):   3.053
CHIP NO6: 51.67   42.15   48.38   47.63   46.09   58.70
   POWER (WATTS):   3.079
CHIP NO7: 48.27   46.25   48.70   48.07   39.78   58.52
   POWER (WATTS):   3.066
CHIP NO8: 49.10   45.58   48.05   00.00   44.02   58.53
   POWER (WATTS):   3.067
CHIP NO9: 50.71   41.39   43.01   43.01   45.34   58.49
   POWER (WATTS):   3.064

HEAT EXCHANGERS TEMPERATURES: RIGHT   CENTER   LEFT
      BOTTOM:                 10.057   10.166   10.176
      TOP:                    10.073   00.000   10.163

BACK PLANE TEMPERATURES  :
T(55):   24.75
T(56):   26.51
T(57):   22.64
T(74):   28.00
T(75):   26.95
T(76):   28.63
T(77):   25.41

SOURCE VOLTAGE:  6.807

VOLTAGE TO THE HEATERS :
CHIP #1:    5.411
CHIP #2:    5.712
CHIP #3:    5.685
CHIP #4:    5.692
CHIP #5:    5.385
CHIP #6:    5.680
CHIP #7:    5.685
CHIP #8:    5.685
CHIP #9:    5.696
```

TABLE 23

REDUCED DATA FOR INPUT POWER 0.1 W
CHAMBER WIDTH = 30 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    10161810
THE POWER SETTING PER CHIP WAS:   0.1 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM
```

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2

```
  1      .10      2.76     23.19     10.85
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
   AVERAGE TEMPERATURE: 12.861
   SINK TEMPERATURE: 10.104

  2      .10      2.82     22.77     10.66
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
   AVERAGE TEMPERATURE: 12.925
   SINK TEMPERATURE: 10.104

  3      .10      3.04     21.32      9.98
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
   AVERAGE TEMPERATURE: 13.144
   SINK TEMPERATURE: 10.104

  4      .10      2.63     24.48     11.46
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
   AVERAGE TEMPERATURE: 12.734
   SINK TEMPERATURE: 10.104

  5      .10      2.83     22.82     10.68
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
   AVERAGE TEMPERATURE: 12.934
   SINK TEMPERATURE: 10.104

  6      .10      2.68     24.11     11.28
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
   AVERAGE TEMPERATURE: 12.788
   SINK TEMPERATURE: 10.104

  7      .10      2.68     24.10     11.28
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
   AVERAGE TEMPERATURE: 12.782
   SINK TEMPERATURE: 10.104

  8      .10      2.99     21.58     10.10
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
   AVERAGE TEMPERATURE: 13.089
   SINK TEMPERATURE: 10.104

  9      .10      3.10     20.84      9.75
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
   AVERAGE TEMPERATURE: 13.202
   SINK TEMPERATURE: 10.104
```

97

TABLE 24

REDUCED DATA FOR INPUT POWER 0.7 W
CHAMBER WIDTH = 30 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    10170950
THE POWER SETTING PER CHIP WAS:   0.7 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM
```

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2

```
 1      .70     11.22     40.87     19.12
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    2.41
   AVERAGE TEMPERATURE: 21.294
   SINK TEMPERATURE: 10.073

 2      .71     10.92     42.23     19.76
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    2.42
   AVERAGE TEMPERATURE: 20.990
   SINK TEMPERATURE: 10.073

 3      .71     12.11     38.48     18.00
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    2.48
   AVERAGE TEMPERATURE: 22.185
   SINK TEMPERATURE: 10.073

 4      .71     11.20     41.37     19.36
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    2.44
   AVERAGE TEMPERATURE: 21.273
   SINK TEMPERATURE: 10.073

 5      .71     11.71     39.73     18.59
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    2.46
   AVERAGE TEMPERATURE: 21.783
   SINK TEMPERATURE: 10.073

 6      .72     11.81     39.61     18.53
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    2.48
   AVERAGE TEMPERATURE: 21.878
   SINK TEMPERATURE: 10.073

 7      .71     10.99     42.38     19.83
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    2.45
   AVERAGE TEMPERATURE: 21.066
   SINK TEMPERATURE: 10.073

 8      .71     11.61     40.07     18.75
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    2.46
   AVERAGE TEMPERATURE: 21.685
   SINK TEMPERATURE: 10.073

 9      .71     11.16     41.64     19.48
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    2.44
   AVERAGE TEMPERATURE: 21.235
   SINK TEMPERATURE: 10.073
```

98

TABLE 25

REDUCED DATA FOR INPUT POWER 1.1 W
CHAMBER WIDTH = 30 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    10171720
THE POWER SETTING PER CHIP WAS:    1.1 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM
```

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2

1   1.08   16.00   44.33   20.74
   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 3.93
   AVERAGE TEMPERATURE: 26.089
   SINK TEMPERATURE: 10.085

2   1.09   15.48   46.12   21.58
   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 3.94
   AVERAGE TEMPERATURE: 25.562
   SINK TEMPERATURE: 10.085

3   1.10   16.83   42.84   20.04
   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 4.03
   AVERAGE TEMPERATURE: 26.917
   SINK TEMPERATURE: 10.085

4   1.09   16.05   44.67   20.90
   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 3.98
   AVERAGE TEMPERATURE: 26.136
   SINK TEMPERATURE: 10.085

5   1.10   17.57   40.98   19.17
   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 4.06
   AVERAGE TEMPERATURE: 27.657
   SINK TEMPERATURE: 10.085

6   1.10   16.42   44.03   20.60
   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 4.03
   AVERAGE TEMPERATURE: 26.509
   SINK TEMPERATURE: 10.085

7   1.10   15.60   46.18   21.60
   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 3.98
   AVERAGE TEMPERATURE: 25.688
   SINK TEMPERATURE: 10.085

8   1.10   16.43   43.88   20.53
   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 4.02
   AVERAGE TEMPERATURE: 26.519
   SINK TEMPERATURE: 10.085

9   1.10   15.63   46.12   21.58
   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 3.98
   AVERAGE TEMPERATURE: 25.717
   SINK TEMPERATURE: 10.085

TABLE 26

REDUCED DATA FOR INPUT POWER 1.5 W
CHAMBER WIDTH = 30 mm

```
THE RAW Emf DATA ARE FROM THE FILE:     10211130
THE POWER SETTING PER CHIP WAS:    1.5 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM
```

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
1	1.52	22.39	44.65	20.89

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 5.94
  AVERAGE TEMPERATURE: 32.569
  SINK TEMPERATURE: 10.180

| 2 | 1.53 | 21.80 | 46.10 | 21.57 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 5.94
  AVERAGE TEMPERATURE: 31.978
  SINK TEMPERATURE: 10.180

| 3 | 1.54 | 24.07 | 42.22 | 19.75 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.15
  AVERAGE TEMPERATURE: 34.252
  SINK TEMPERATURE: 10.180

| 4 | 1.54 | 22.27 | 45.37 | 21.23 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.00
  AVERAGE TEMPERATURE: 32.450
  SINK TEMPERATURE: 10.180

| 5 | 1.54 | 23.39 | 43.35 | 20.28 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.09
  AVERAGE TEMPERATURE: 33.574
  SINK TEMPERATURE: 10.180

| 6 | 1.55 | 22.61 | 45.06 | 21.08 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.07
  AVERAGE TEMPERATURE: 32.788
  SINK TEMPERATURE: 10.180

| 7 | 1.54 | 21.66 | 46.86 | 21.92 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 5.99
  AVERAGE TEMPERATURE: 31.837
  SINK TEMPERATURE: 10.180

| 8 | 1.54 | 22.30 | 45.54 | 21.30 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.03
  AVERAGE TEMPERATURE: 32.482
  SINK TEMPERATURE: 10.180

| 9 | 1.54 | 20.60 | 49.26 | 23.05 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 5.92
  AVERAGE TEMPERATURE: 30.782
  SINK TEMPERATURE: 10.180

TABLE 27

REDUCED DATA FOR INPUT POWER 2.5 W
CHAMBER WIDTH = 30 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    10182338
THE POWER SETTING PER CHIP WAS:    2.5 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM
```

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
1	2.44	31.61	51.08	23.90

   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.54
   AVERAGE TEMPERATURE: 41.698
   SINK TEMPERATURE: 10.087

| 2 | 2.45 | 30.24 | 53.65 | 25.10 |

   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.44
   AVERAGE TEMPERATURE: 40.331
   SINK TEMPERATURE: 10.087

| 3 | 2.48 | 33.03 | 49.69 | 23.25 |

   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.86
   AVERAGE TEMPERATURE: 43.113
   SINK TEMPERATURE: 10.087

| 4 | 2.46 | 31.27 | 52.14 | 24.39 |

   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.60
   AVERAGE TEMPERATURE: 41.356
   SINK TEMPERATURE: 10.087

| 5 | 2.47 | 32.19 | 50.86 | 23.79 |

   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.74
   AVERAGE TEMPERATURE: 42.277
   SINK TEMPERATURE: 10.087

| 6 | 2.49 | 31.14 | 52.84 | 24.72 |

   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.68
   AVERAGE TEMPERATURE: 41.225
   SINK TEMPERATURE: 10.087

| 7 | 2.48 | 30.10 | 54.39 | 25.14 |

   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.52
   AVERAGE TEMPERATURE: 40.189
   SINK TEMPERATURE: 10.087

| 8 | 2.48 | 30.94 | 52.97 | 24.78 |

   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.62
   AVERAGE TEMPERATURE: 41.023
   SINK TEMPERATURE: 10.087

| 9 | 2.48 | 28.94 | 56.51 | 26.44 |

   FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.39
   AVERAGE TEMPERATURE: 39.028
   SINK TEMPERATURE: 10.087

101

TABLE 28

REDUCED DATA FOR INPUT POWER 3.0 W
CHAMBER WIDTH = 30 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    10191310
THE POWER SETTING PER CHIP WAS:    3.0 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP    QNET(W)  Tavg-Ts      Nu1        Nu2

  1      2.96     38.29      51.36      24.03
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   13.73
   AVERAGE TEMPERATURE: 48.440
   SINK TEMPERATURE: 10.154

  2      2.98     36.50      54.14      25.33
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   13.56
   AVERAGE TEMPERATURE: 46.657
   SINK TEMPERATURE: 10.154

  3      3.01     38.80      51.50      24.10
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   14.03
   AVERAGE TEMPERATURE: 48.959
   SINK TEMPERATURE: 10.154

  4      2.99     38.03      52.27      24.46
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   13.85
   AVERAGE TEMPERATURE: 48.185
   SINK TEMPERATURE: 10.154

  5      3.00     38.62      51.66      24.17
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   13.98
   AVERAGE TEMPERATURE: 48.777
   SINK TEMPERATURE: 10.154

  6      3.02     36.60      54.74      25.61
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   13.76
   AVERAGE TEMPERATURE: 46.755
   SINK TEMPERATURE: 10.154

  7      3.01     36.49      54.71      25.60
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   13.69
   AVERAGE TEMPERATURE: 46.642
   SINK TEMPERATURE: 10.154

  8      3.01     36.62      54.55      25.52
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   13.72
   AVERAGE TEMPERATURE: 46.771
   SINK TEMPERATURE: 10.154

  9      3.01     33.27      59.88      28.01
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   13.23
   AVERAGE TEMPERATURE: 43.421
   SINK TEMPERATURE: 10.154
```

TABLE 29

TEMPERATURE DATA FOR INPUT POWER 0.1 W
CHAMBER WIDTH = 9 mm

```
RESULTS ARE STORED IN FILE: 11050029

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF:    22.78
BATH TEMP  :   10 C
TEMPERATURE READINGS IN DEGREES CELSIUS
          CENTER   TOP    RIGHT   LEFT   BOTTOM   BACK
CHIP NO1: 14.34   14.25   14.16   14.24   14.08   14.40
    POWER (WATTS):   .097
CHIP NO2: 14.48   14.33   14.32   14.32   14.22   14.54
    POWER (WATTS):   .098
CHIP NO3: 14.58   14.53   14.49   14.48   14.54   14.64
    POWER (WATTS):   .0989
CHIP NO4: 14.39   14.25   14.10   14.12   14.02   14.45
    POWER (WATTS):   .099
CHIP NO5: 14.43   15.89   14.33   14.37   14.26   14.49
    POWER (WATTS):   .099
CHIP NO6: 14.65   14.37   00.00   14.24   14.58   14.71
    POWER (WATTS):   .099
CHIP NO7: 14.13   14.14   14.19   14.17   14.08   14.19
    POWER (WATTS):   .099
CHIP NO8: 14.59   14.41   14.42   00.00   14.24   14.65
    POWER (WATTS):   .099
CHIP NO9: 14.71   14.28   16.01   16.01   14.45   14.77
    POWER (WATTS):   .099

HEAT EXCHANGERS TEMPERATURES: RIGHT   CENTER   LEFT
     BOTTOM:                  09.914   09.967   09.965
     TOP:                     10.011   00.000   10.392

BACK PLANE TEMPERATURES  :
T(55):   12.97
T(56):   13.12
T(74):   13.52
T(75):   13.83
T(76):   13.99
T(77):   13.25

SOURCE VOLTAGE: 1.219

VOLTAGE TO THE HEATERS :
CHIP #1:    .967
CHIP #2:   1.021
CHIP #3:   1.016
CHIP #4:   1.017
CHIP #5:    .962
CHIP #6:   1.015
CHIP #7:   1.015
CHIP #8:   1.015
CHIP #9:   1.016
```

TABLE 30

TEMPERATURE DATA FOR INPUT POWER 0.7 W
CHAMBER WIDTH = 9 mm

```
RESULTS ARE STORED IN FILE: 11062057

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF:    20.61
BATH TEMP  :   10 C
TEMPERATURE READINGS IN DEGREES CELSIUS
          CENTER    TOP    RIGHT    LEFT   BOTTOM   BACK
CHIP NO1: 23.48   23.27   22.85   23.21   21.49   23.88
    POWER (WATTS):    .696
CHIP NO2: 24.85   23.75   23.74   23.74   23.07   25.26
    POWER (WATTS):    .701
CHIP NO3: 24.78   24.57   24.32   23.70   24.51   25.19
    POWER (WATTS):    .7050
CHIP NO4: 23.92   22.97   22.82   22.78   21.97   24.32
    POWER (WATTS):    .703
CHIP NO5: 24.77   23.82   24.12   24.42   23.69   25.17
    POWER (WATTS):    .705
CHIP NO6: 25.92   23.76   00.00   23.15   25.35   26.33
    POWER (WATTS):    .709
CHIP NO7: 23.12   22.57   23.13   22.84   21.02   23.53
    POWER (WATTS):    .707
CHIP NO8: 24.84   23.90   23.94   00.00   22.83   25.25
    POWER (WATTS):    .707
CHIP NO9: 25.78   22.75   19.26   23.34   24.30   26.19
    POWER (WATTS):    .706

HEAT EXCHANGERS TEMPERATURES: RIGHT   CENTER    LEFT
    BOTTOM:                   09.972  10.070  10.088
    TOP:                      10.047  00.000  10.137

BACK PLANE TEMPERATURES  :
T(55):   15.17
T(56):   15.45
T(74):   15.92
T(75):   15.99
T(76):   16.29
T(77):   15.68

SOURCE VOLTAGE:  3.259

VOLTAGE TO THE HEATERS :
CHIP #1:    2.587
CHIP #2:    2.731
CHIP #3:    2.720
CHIP #4:    2.722
CHIP #5:    2.575
CHIP #6:    2.717
CHIP #7:    2.718
CHIP #8:    2.718
CHIP #9:    2.720
```

TABLE 31

TEMPERATURE DATA FOR INPUT POWER 1.1 W
CHAMBER WIDTH = 9 mm

```
RESULTS ARE STORED IN FILE:  11022255

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF:    21.11
BATH TEMP  :   10 C
TEMPERATURE READINGS IN DEGREES CELSIUS
           CENTER    TOP   RIGHT    LEFT   BOTTOM    BACK
CHIP NO1:  28.92   28.61   28.26   28.57   25.77   29.87
   POWER (WATTS):   1.093
CHIP NO2:  31.27   29.86   29.60   29.60   28.52   29.97
   POWER (WATTS):   1.100
CHIP NO3:  30.49   30.42   30.02   28.65   30.37   30.08
   POWER (WATTS):   1.1071
CHIP NO4:  29.63   28.45   28.11   27.89   26.78   30.04
   POWER (WATTS):   1.104
CHIP NO5:  31.16   29.79   30.20   30.63   29.54   30.08
   POWER (WATTS):   1.107
CHIP NO6:  31.91   28.89   00.00   28.72   31.17   30.18
   POWER (WATTS):   1.114
CHIP NO7:  28.48   27.51   28.46   28.34   25.07   30.15
   POWER (WATTS):   1.112
CHIP NO8:  31.20   30.08   30.00   00.00   28.01   30.14
   POWER (WATTS):   1.111
CHIP NO9:  32.68   28.26   31.03   31.03   30.57   30.11
   POWER (WATTS):   1.110

HEAT EXCHANGERS TEMPERATURES: RIGHT  CENTER    LEFT
       BOTTOM:                09.839  10.128  10.241
       TOP:                   09.863  00.000  09.952

BACK PLANE TEMPERATURES  :
T(55):   17.38
T(56):   17.58
T(74):   18.00
T(75):   18.02
T(76):   18.41
T(77):   17.63

SOURCE VOLTAGE:  4.086

VOLTAGE TO THE HEATERS :
CHIP #1:    3.244
CHIP #2:    3.425
CHIP #3:    3.411
CHIP #4:    3.413
CHIP #5:    3.229
CHIP #6:    3.406
CHIP #7:    3.407
CHIP #8:    3.408
CHIP #9:    3.409
```

TABLE 32

TEMPERATURE DATA FOR INPUT POWER 1.5 W
CHAMBER WIDTH = 9 mm

```
RESULTS ARE STORED IN FILE:  11091225

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF:     21.83
BATH TEMP :    10 C

TEMPERATURE READINGS IN DEGREES CELSIUS
           CENTER    TOP   RIGHT   LEFT  BOTTOM   BACK
CHIP NO1: 36.71    36.38   35.78  36.25  32.76   37.56
   POWER (WATTS):   1.489
CHIP NO2: 38.97    36.79   37.06  37.06  35.88   39.83
   POWER (WATTS):   1.497
CHIP NO3: 38.33    37.92   37.67  34.98  37.83   39.20
   POWER (WATTS):   1.5093
CHIP NO4: 37.06    35.37   35.16  34.59  33.41   37.92
   POWER (WATTS):   1.504
CHIP NO5: 38.29    36.57   37.19  37.75  36.20   39.16
   POWER (WATTS):   1.508
CHIP NO6: 39.40    35.38   00.00  34.97  38.23   40.27
   POWER (WATTS):   1.516
CHIP NO7: 34.94    33.67   35.04  34.46  30.18   35.81
   POWER (WATTS):   1.512
CHIP NO8: 38.19    35.83   36.98  00.00  34.50   39.05
   POWER (WATTS):   1.512
CHIP NO9: 39.71    34.80   28.60  36.52  36.09   40.58
   POWER (WATTS):   1.511

HEAT EXCHANGERS TEMPERATURES: RIGHT   CENTER   LEFT
      BOTTOM:                 09.828  09.977  10.040
      TOP:                    10.007  00.000  10.295

BACK PLANE TEMPERATURES  :
T(55):   20.82
T(56):   21.73
T(74):   22.48
T(75):   22.33
T(76):   22.64
T(77):   21.31

SOURCE VOLTAGE:  4.771

VOLTAGE TO THE HEATERS :
CHIP #1:    3.789
CHIP #2:    4.000
CHIP #3:    3.983
CHIP #4:    3.987
CHIP #5:    3.772
CHIP #6:    3.979
CHIP #7:    3.981
CHIP #8:    3.982
CHIP #9:    3.983
```

TABLE 33

TEMPERATURE DATA FOR INPUT POWER 2.5 W
CHAMBER WIDTH = 9 mm

```
     RESULTS ARE STORED IN FILE:  11082020

     EXPERIMENT CARRIED OUT AT
     AMBIENT TEMP (CELSIUS) OF:    21.28
     BATH TEMP :    10 C
     TEMPERATURE READINGS IN DEGREES CELSIUS
            CENTER     TOP    RIGHT    LEFT   BOTTOM    BACK
CHIP NO1: 46.62    45.93    45.41    46.08    40.22    48.05
     POWER (WATTS):   2.504
CHIP NO2: 50.04    46.15    47.23    47.23    43.85    51.48
     POWER (WATTS):   2.520
CHIP NO3: 48.91    48.75    48.04    45.63    48.30    50.37
     POWER (WATTS):   2.5388
CHIP NO4: 47.00    43.52    44.22    42.84    41.35    48.45
     POWER (WATTS):   2.531
CHIP NO5: 48.77    46.61    47.23    48.29    45.89    50.23
     POWER (WATTS):   2.538
CHIP NO6: 49.99    44.34    00.00    44.08    48.13    51.45
     POWER (WATTS):   2.552
CHIP NO7: 43.36    41.13    43.65    42.69    35.63    44.82
     POWER (WATTS):   2.544
CHIP NO8: 48.86    45.42    47.09    00.00    43.17    50.32
     POWER (WATTS):   2.544
CHIP NO9: 49.89    42.54    34.29    45.52    45.93    51.35
     POWER (WATTS):   2.541

     HEAT EXCHANGERS TEMPERATURES: RIGHT   CENTER    LEFT
            BOTTOM:                09.859   10.037   10.110
            TOP:                   09.803   00.000   10.073

     BACK PLANE TEMPERATURES   :
     T(55):   22.95
     T(56):   24.01
     T(74):   24.80
     T(75):   24.59
     T(76):   24.97
     T(77):   23.67

     SOURCE VOLTAGE:  6.193

     VOLTAGE TO THE HEATERS :
     CHIP #1:    4.921
     CHIP #2:    5.193
     CHIP #3:    5.172
     CHIP #4:    5.176
     CHIP #5:    4.897
     CHIP #6:    5.165
     CHIP #7:    5.169
     CHIP #8:    5.169
     CHIP #9:    5.171
```

TABLE 34

TEMPERATURE DATA FOR INPUT POWER 3.0 W
CHAMBER WIDTH = 9 mm

```
RESULTS ARE STORED IN FILE: 11072058

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF:    21.00
BATH TEMP  :   10 C
TEMPERATURE READINGS IN DEGREES CELSIUS
          CENTER    TOP    RIGHT   LEFT   BOTTOM    BACK
CHIP NO1: 55.97   54.46   55.08   55.59   45.61   57.66
     POWER (WATTS):   2.938
CHIP NO2: 61.12   57.34   58.19   58.19   54.57   62.82
     POWER (WATTS):   2.957
CHIP NO3: 58.47   58.54   57.89   55.35   58.30   60.18
     POWER (WATTS):   2.9774
CHIP NO4: 57.35   53.88   54.52   54.33   49.46   59.05
     POWER (WATTS):   2.969
CHIP NO5: 58.98   57.68   58.44   59.12   56.79   60.69
     POWER (WATTS):   2.978
CHIP NO6: 61.17   55.49   00.00   55.89   59.33   62.89
     POWER (WATTS):   2.993
CHIP NO7: 52.97   51.59   53.54   53.26   43.41   54.68
     POWER (WATTS):   2.984
CHIP NO8: 60.57   57.20   59.10   00.00   54.97   62.28
     POWER (WATTS):   2.985
CHIP NO9: 60.45   53.52   46.33   56.95   56.66   62.17
     POWER (WATTS):   2.984

HEAT EXCHANGERS TEMPERATURES: RIGHT   CENTER   LEFT
     BOTTOM:                  09.783   10.022   10.176
     TOP:                     09.816   00.000   10.063

BACK PLANE TEMPERATURES  :
T(55):   32.35
T(56):   34.45
T(74):   35.59
T(75):   35.08
T(76):   35.20
T(77):   33.52

SOURCE VOLTAGE:  6.715

VOLTAGE TO THE HEATERS :
CHIP #1:    5.339
CHIP #2:    5.633
CHIP #3:    5.611
CHIP #4:    5.615
CHIP #5:    5.314
CHIP #6:    5.603
CHIP #7:    5.608
CHIP #8:    5.607
CHIP #9:    5.608
```

TABLE 35

REDUCED DATA FOR INPUT POWER 0.1 W
CHAMBER WIDTH = 9 mm

THE RAW Emf DATA ARE FROM THE FILE: 11050029
THE POWER SETTING PER CHIP WAS: 0.1 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
1	.10	4.10	15.19	7.11

FLUX BASED RAYLEIGH NUMBER * E-9 IS: .30
AVERAGE TEMPERATURE: 14.242
SINK TEMPERATURE: 10.139

2	.10	4.08	15.38	7.19

FLUX BASED RAYLEIGH NUMBER * E-9 IS: .31
AVERAGE TEMPERATURE: 14.221
SINK TEMPERATURE: 10.139

3	.10	4.39	14.43	6.75

FLUX BASED RAYLEIGH NUMBER * E-9 IS: .31
AVERAGE TEMPERATURE: 14.525
SINK TEMPERATURE: 10.139

4	.10	4.07	15.54	7.27

FLUX BASED RAYLEIGH NUMBER * E-9 IS: .31
AVERAGE TEMPERATURE: 14.208
SINK TEMPERATURE: 10.139

5	.10	4.36	14.52	6.80

FLUX BASED RAYLEIGH NUMBER * E-9 IS: .31
AVERAGE TEMPERATURE: 14.497
SINK TEMPERATURE: 10.139

6	.10	4.33	14.70	6.88

FLUX BASED RAYLEIGH NUMBER * E-9 IS: .31
AVERAGE TEMPERATURE: 14.473
SINK TEMPERATURE: 10.139

7	.10	4.01	15.86	7.42

FLUX BASED RAYLEIGH NUMBER * E-9 IS: .31
AVERAGE TEMPERATURE: 14.153
SINK TEMPERATURE: 10.139

8	.10	4.33	14.67	6.86

FLUX BASED RAYLEIGH NUMBER * E-9 IS: .31
AVERAGE TEMPERATURE: 14.471
SINK TEMPERATURE: 10.139

9	.10	4.52	14.00	6.55

FLUX BASED RAYLEIGH NUMBER * E-9 IS: .31
AVERAGE TEMPERATURE: 14.660
SINK TEMPERATURE: 10.139

TABLE 36

REDUCED DATA FOR INPUT POWER 0.7 W
CHAMBER WIDTH = 9 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    11062057
THE POWER SETTING PER CHIP WAS:   0.7 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM
```

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
1	.68	13.03	34.38	16.08

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.41
  AVERAGE TEMPERATURE: 23.174
  SINK TEMPERATURE: 10.145

| 2 | .69 | 13.11 | 34.42 | 16.10 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.43
  AVERAGE TEMPERATURE: 23.251
  SINK TEMPERATURE: 10.145

| 3 | .69 | 14.31 | 31.75 | 14.86 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.48
  AVERAGE TEMPERATURE: 24.456
  SINK TEMPERATURE: 10.145

| 4 | .69 | 13.07 | 34.63 | 16.20 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.44
  AVERAGE TEMPERATURE: 23.219
  SINK TEMPERATURE: 10.145

| 5 | .69 | 14.31 | 31.75 | 14.86 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.48
  AVERAGE TEMPERATURE: 24.451
  SINK TEMPERATURE: 10.145

| 6 | .70 | 14.65 | 31.20 | 14.60 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.50
  AVERAGE TEMPERATURE: 24.794
  SINK TEMPERATURE: 10.145

| 7 | .70 | 12.79 | 35.62 | 16.66 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.44
  AVERAGE TEMPERATURE: 22.933
  SINK TEMPERATURE: 10.145

| 8 | .70 | 14.17 | 32.16 | 15.04 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.48
  AVERAGE TEMPERATURE: 24.313
  SINK TEMPERATURE: 10.145

| 9 | .69 | 13.12 | 34.64 | 16.21 |

  FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.45
  AVERAGE TEMPERATURE: 23.266
  SINK TEMPERATURE: 10.145

TABLE 37

REDUCED DATA FOR INPUT POWER 1.1 W
CHAMBER WIDTH = 9 mm

```
THE RAW Emf DATA ARE FROM THE FILE:   11022255
THE POWER SETTING PER CHIP WAS:  1.1 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP   QNET(W)  Tavg-Ts      Nu1        Nu2

 1      1.08    18.18      38.87      18.19
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   4.02
        AVERAGE TEMPERATURE: 28.377
        SINK TEMPERATURE: 10.193

 2      1.08    18.63      38.19      17.87
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   4.07
        AVERAGE TEMPERATURE: 28.825
        SINK TEMPERATURE: 10.193

 3      1.09    19.71      36.38      17.02
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   4.14
        AVERAGE TEMPERATURE: 29.898
        SINK TEMPERATURE: 10.193

 4      1.09    18.29      33.06      18.28
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   4.07
        AVERAGE TEMPERATURE: 28.480
        SINK TEMPERATURE: 10.193

 5      1.09    20.35      35.26      16.49
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   4.17
        AVERAGE TEMPERATURE: 30.538
        SINK TEMPERATURE: 10.193

 6      1.10    20.24      35.66      16.68
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   4.19
        AVERAGE TEMPERATURE: 30.429
        SINK TEMPERATURE: 10.193

 7      1.10    17.88      40.23      18.82
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   4.08
        AVERAGE TEMPERATURE: 28.076
        SINK TEMPERATURE: 10.193

 8      1.10    20.13      35.76      16.73
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   4.18
        AVERAGE TEMPERATURE: 30.321
        SINK TEMPERATURE: 10.193

 9      1.09    19.19      37.43      17.51
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   4.13
        AVERAGE TEMPERATURE: 29.382
        SINK TEMPERATURE: 10.193
```

111

TABLE 38

REDUCED DATA FOR INPUT POWER 1.5 W
CHAMBER WIDTH = 9 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    11091225
THE POWER SETTING PER CHIP WAS:   1.5 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP   QNET(W)  Tavg-Ts      Nu1       Nu2

  1      1.47     25.92      37.30     17.45
       FLUX BASED RAYLEIGH NUMBER * E-9 IS:   5.96
       AVERAGE TEMPERATURE: 36.108
       SINK TEMPERATURE: 10.186

  2      1.47     25.87      37.60     17.59
       FLUX BASED RAYLEIGH NUMBER * E-9 IS:   6.00
       AVERAGE TEMPERATURE: 36.053
       SINK TEMPERATURE: 10.186

  3      1.49     27.17      36.12     16.90
       FLUX BASED RAYLEIGH NUMBER * E-9 IS:   6.13
       AVERAGE TEMPERATURE: 37.353
       SINK TEMPERATURE: 10.186

  4      1.48     25.44      38.39     17.96
       FLUX BASED RAYLEIGH NUMBER * E-9 IS:   5.99
       AVERAGE TEMPERATURE: 35.625
       SINK TEMPERATURE: 10.186

  5      1.49     27.48      35.69     16.70
       FLUX BASED RAYLEIGH NUMBER * E-9 IS:   6.15
       AVERAGE TEMPERATURE: 37.664
       SINK TEMPERATURE: 10.186

  6      1.49     27.26      36.16     16.92
       FLUX BASED RAYLEIGH NUMBER * E-9 IS:   6.17
       AVERAGE TEMPERATURE: 37.450
       SINK TEMPERATURE: 10.186

  7      1.49     24.25      40.46     18.93
       FLUX BASED RAYLEIGH NUMBER * E-9 IS:   5.95
       AVERAGE TEMPERATURE: 34.440
       SINK TEMPERATURE: 10.186

  8      1.49     27.02      36.36     17.01
       FLUX BASED RAYLEIGH NUMBER * E-9 IS:   6.13
       AVERAGE TEMPERATURE: 37.211
       SINK TEMPERATURE: 10.186

  9      1.49     25.41      38.61     18.07
       FLUX BASED RAYLEIGH NUMBER * E-9 IS:   6.02
       AVERAGE TEMPERATURE: 35.592
       SINK TEMPERATURE: 10.186
```

TABLE 39

REDUCED DATA FOR INPUT POWER 2.5 W
CHAMBER WIDTH = 9 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    11082020
THE POWER SETTING PER CHIP WAS:   2.5 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP   QNET(W)   Tavg-Ts      Nu1        Nu2

 1      2.47     35.42      46.27      21.65
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:    11.15
        AVERAGE TEMPERATURE: 45.692
        SINK TEMPERATURE: 10.271

 2      2.49     35.23      46.82      21.90
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:    11.20
        AVERAGE TEMPERATURE: 45.503
        SINK TEMPERATURE: 10.271

 3      2.50     37.64      44.23      20.69
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:    11.58
        AVERAGE TEMPERATURE: 47.908
        SINK TEMPERATURE: 10.271

 4      2.50     34.33      48.22      22.56
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:    11.14
        AVERAGE TEMPERATURE: 44.605
        SINK TEMPERATURE: 10.271

 5      2.50     37.68      44.17      20.66
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:    11.58
        AVERAGE TEMPERATURE: 47.946
        SINK TEMPERATURE: 10.271

 6      2.52     37.02      45.18      21.14
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:    11.56
        AVERAGE TEMPERATURE: 47.287
        SINK TEMPERATURE: 10.271

 7      2.51     32.27      51.53      24.11
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:    10.96
        AVERAGE TEMPERATURE: 42.536
        SINK TEMPERATURE: 10.271

 8      2.51     37.08      44.97      21.04
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:    11.53
        AVERAGE TEMPERATURE: 47.355
        SINK TEMPERATURE: 10.271

 9      2.51     33.79      49.19      23.01
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:    11.12
        AVERAGE TEMPERATURE: 44.057
        SINK TEMPERATURE: 10.271
```

TABLE 40

REDUCED DATA FOR INPUT POWER 3.0 W
CHAMBER WIDTH = 9 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    11072058
THE POWER SETTING PER CHIP WAS:   3.0 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM
```

```
CHIP   QNET(W)   Tavg-Ts      Nu1       Nu2

  1     2.90      44.40      43.64      20.42
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   14.41
        AVERAGE TEMPERATURE: 54.762
        SINK TEMPERATURE: 10.362

  2     2.92      46.34      42.14      19.72
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   14.79
        AVERAGE TEMPERATURE: 56.697
        SINK TEMPERATURE: 10.362

  3     2.94      47.28      41.61      19.47
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   15.04
        AVERAGE TEMPERATURE: 57.639
        SINK TEMPERATURE: 10.362

  4     2.93      44.68      43.84      20.51
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   14.61
        AVERAGE TEMPERATURE: 55.040
        SINK TEMPERATURE: 10.362

  5     2.94      48.33      40.74      19.06
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   15.20
        AVERAGE TEMPERATURE: 58.691
        SINK TEMPERATURE: 10.362

  6     2.96      48.31      40.97      19.17
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   15.28
        AVERAGE TEMPERATURE: 58.676
        SINK TEMPERATURE: 10.362

  7     2.95      42.01      46.78      21.89
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   14.29
        AVERAGE TEMPERATURE: 52.372
        SINK TEMPERATURE: 10.362

  8     2.95      48.82      40.44      18.92
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   15.31
        AVERAGE TEMPERATURE: 59.183
        SINK TEMPERATURE: 10.362

  9     2.95      44.89      43.86      20.52
        FLUX BASED RAYLEIGH NUMBER * E-9 IS:   14.71
        AVERAGE TEMPERATURE: 55.253
        SINK TEMPERATURE: 10.362
```

114

SOFTWARE LISTING

```
!     !*************************
10    ! PROGRAM  CalcDiel    *
20    !*************************
21    !
23    ! EDITED BY LT E. TORRES. FROM ORIGINALS OF
30    ! PAMUK [REF.12] AND BENEDICT [REF. 13]
31    !
40    !*****************************************
50    ! THIS PROGRAM ANALYSES THE DATA READ FROM *
60    ! A DATA FILE DESIGNATED BY THE OPERATOR. IT*
70    ! REDUCES THE DATA TO CALCULATIONS OF NET   *
80    ! POWER. RAYLEIGH NUMBER AND NUSELT NUMBER.  *
90    !*****************************************
91    !
93    ! VARIABLES USED ARE :
94    ! EMF : VOLTAGE FROM THE THERMOCOUPLE'S.
95    ! POWER : POWER DISSIPATED BY THE HEATERS.
96    ! T(I)  : TEMPERATURE CONVERTED FROM THERMOCOU-
97    !           PLES VOLTAGE.
98    ! TAVG  : IS THE AVERAGE TEMPERATURE OF THE
99    !           CHIP. IT IS OBTAINED MULTIPLYING
100   !           THE TEMPERATURE FOUND IN EACH FACE
101   !           BY THE AREA AND DIVIDING BY THE TO-
102   !           TAL AREA.
104   ! Is   : CHIP BACK SURFACE TEMPERATURE.
105   ! Tfilm: FILM TEMPERATURE OF THE FC-75.
106   ! QNET : ELECTRIC POWER MINUS CONDUCTION LOSSES.
107   ! TSINK: AVERAGE OF THE 6 THERMOCOUPLES IN
108   !           THE UPPER AND LOWER HEAT-EXCHANGERS.
109   ! NU1 : VERTICAL LENGTH BASED NUSSELT NUMBER
110   ! NU2 : AREA-PERIMETER BASED NUSSELT NUMBER.
111   ! OTHER VARIABLES ARE SELF EXPLANATORIES.
113   !*****************************************
114   !
115   COM /Co/ D(7)
116   !
120   DIM Emf(76),Power(9),T(76),Tavg(9),Is(9)
130   DIM Tfilm(9),Qnet(9),H(9),k(9),Rho(9),Cp(9)
140   DIM N(9),Nu(9),Ra(9),Delt(9),Alfa(9),Pr(9)
150   DIM Gr(9),Beta(9),Dpow(9),Dts(9),Rp(6)
160   !
170   ! CORRELATION FACTORS TO CONVERT Emf TO DEGREES CELSIUS.
180   DATA 0.10086091,25727.9,-767345.8,78025596.
190   DATA -3247486589,6.38E11,-2.66E13,3.94E14
191   DATA 2.50,2.06,2.08,2.08,2.50,2.08,2.08,2.08,2.08
200   !
210   READ D(*)
211   READ Rp(*)
220   !
250   PRINTER IS 701
270   BEEP
280   BEEP
290   !
300   INPUT "ENTER THE NAME OF THE FILE CONTAINING DATA",Oldfile$
301   !
310   PRINT USING "10X,""THE RAW Emf DATA ARE FROM THE FILE:   "",10A":Oldfile$
311   !
320   INPUT "ENTER THE POWER SETTING ",Power$
330   !
```

115

```
340    PRINT USING "9X,"" THE POWER SETTING PER CHIP WAS:   "",10A";Powers
341    !
343    PRINT USING "10X,""THE DISTANCE TO THE FRONT WALL WAS 9 MM """
344    !
350    PRINT
370    !
380    BEEP
390    BEEP
400    ASSIGN #File TO Oldfile$
401    ENTER #File;Emf(*)
410    !
420    !**********************************
430    ! CONVERT Emf TO DEGREES CELSIUS  *
431    !**********************************
432    !
440    FOR I=0 TO 60
450    Sum=0
460    FOR J=0 TO 7
470    Sum=Sum+D(J)*Emf(I)^J
480    NEXT J
490    T(I)=Sum
500    NEXT I
502    FOR I=71 TO 76
503    Sum=0
504    FOR J=0 TO 7
506    Sum=Sum+D(J)*Emf(I)^J
508    NEXT J
509    T(I)=Sum
510    NEXT I
511    !
513    !**********************************
520    ! CONVERT Emf TO POWER  *
521    !**********************************
522    !
530    J=1
540    Volt=Emf(61)
550    FOR I=62 TO 70
560    Power(J)=Emf(I)*(Volt-Emf(I))/Rp*I-52)
580    J=J+1
590    NEXT I
591    !
600    !**********************************
610    ! AREA OF THE BLOCK FACES  *
611    !**********************************
612    !
620    Acen=1.92E-4
630    Alef=1.44E-4
640    Arig=1.44E-4
650    Atop=4.8E-5
660    Abot=4.8E-5
670    Atot=5.76E-4
671    !
680    !**********************************************************
690    !CALCULATE THE AVERAGE TEMPERATURES OF THE BLOCK FACES  *
691    !IF A THERMOCOUPLE IS FOUND OPENED,IT SHOULD BE TAKEN OFF.*
700    !**********************************************************
701    !
710    Tavg(1)=(T(0)*Acen+T(1)*Atop+T(2)*Arig+T(3)*Alef+T(4)*Abot)/Atot
720    Tavg(2)=(T(6)*Acen+T(7)*Atop+T(8)*Arig+T(9)*Alef+T(10)*Abot)/Atot
```

116

```
740    Tavg(4)=(T(18)*Acen+T(19)*Atop+T(20)*Arig+T(21)*Alef+T(22)*Abot)/Atot
750    Tavg(5)=(T(24)*Acen+T(25)*Atop+T(26)*Arig+T(27)*Alef+T(28)*Abot)/Atot
760    Tavg(6)=(T(30)*Acen+T(31)*Atop+T(33)*Alef+T(34)*Abot)/(Atot-Arig)
770    Tavg(7)=(T(36)*Acen+T(37)*Atop+T(38)*Arig+T(39)*Alef+T(40)*Abot)/Atot
780    Tavg(8)=(T(42)*Acen+T(43)*Atop+T(44)*Arig+T(46)*Abot)/(Atot-Alef)
790    Tavg(9)=(T(48)*Acen+T(49)*Atop+T(50)*Arig+T(51)*Alef+T(52)*Abot)/Atot
800    !************************************************
850    ! RESISTANCE OF PLEXIGLASS. FOUND WITH A CONDUCTIVITY OF *
852    ! 0.195 W/m.K AND A LENGTH OF 19.5 MM.
853    !
860    Rc=520.83
880    !
881    !************************************************
890    ! CHIP BACK SURFACE TEMPERATURES *
891    !************************************************
900    Ts(1)=T(5)
910    Ts(2)=T(11)
920    Ts(3)=T(17)
930    Ts(4)=T(23)
940    Ts(5)=T(29)
950    Ts(6)=T(35)
960    Ts(7)=T(41)
970    Ts(8)=T(47)
980    Ts(9)=T(53)
990    Tssum=0
1000   FOR J=1 TO 9
1010   Tssum=Tssum+Ts(J)
1020   NEXT J
1030   !
1040   Tsavg=Tssum/9
1041   !
1050   !************************************************
1060   ! CONDUCTION LOSS CALCULATION. *
1061   !************************************************
1062   !
1070   Qloss3=(T(17)-T(75))/Rc
1080   Qloss5=(T(29)-T(55))/Rc
1090   Qloss7=(T(41)-T(54))/Rc
1100   Qloss=(Qloss3+Qloss5+Qloss7)/3
1110   !
1120   !************************************************
1130   ! AVERAGE SINK TEMPERATURE CALCULATION *
1131   !************************************************
1132   !
1140   Tsink=(T(57)+T(58)+T(59)+T(60)+T(71)+T(72))/6
1150   !
1152   ! TWO CHARACTERISTIC LENGTHS WILL BE USED TOCALCULATE NUSSELT NUMBERS :
1153   ! L1 BASED IN THE VERTICAL DIMENSION OF THE CHIP (24.MM)
1154   ! AND L2 BASED IN  THE SUMATION OF THE AREASDIVIDED BY THE PERIMETER.
1155   !
1160   L1=2.40E-2
1161   L2=(2.*16.*24./60.)+2.*(8.*6./29.)+8.*24./54.)*.001
1170   !************************************************
1171   !
1173   !************************************************
1174   ! TO PRINT THE OUTPUT HEADINGS. *
1175   !************************************************
1176   !
1180   PRINT USING "9X,""CHIP   QNET(W) Tavg-Ts    Nu1      Nu2   "",10A"
1200   PRINT
1210   !************************************************
```

117

```
1220    ! CALCULATION OF NET POWER, Nu AND  Ra. *
1230    !*********************************
1231    !
1240    FOR J=1 TO 9
1250    !
1260    ! CALCULATION OF Qnet
1270    Qnet(J)=Power(J)-Qloss
1290    !
1300    ! CALCULATION OF Tfilm
1310    Tfilm(J)=(Tavg(J)+Tsink)/2
1330    !
1340    ! CALCULATION OF A DELTA TEMPERATURE
1350    Delt(J)=Tavg(J)-Tsink
1370    !
1380    ! CALCULATION OF CONVECTION COEFFICIENT
1390    H(J)=Qnet(J)/(Atot*Delt(J))
1410    !
1420    ! CALCULATION OF FC-75 THERMAL CONDUCTIVITY.
1430    K(J)=(.65-7.89474E-4*Tfilm(J))/10
1440    !
1450    ! CALCULATION OF FC-75 DENSITY
1460    Rho(J)=(1.825-.00246*Tfilm(J))*1000
1470    !
1480    ! CALCULATION OF FC-75 SPECIFIC HEAT
1490    Cp(J)=(.241111+3.7037E-4*Tfilm(J))*4180
1500    !
1510    ! CALCULATION OF FC-75 VISCOSITY
1520    N(J)=1.4074-2.964E-2*Tfilm(J)+3.8018E-4*Tfilm(J)^2-2.7308E-6*Tfilm(J)^3+8.
1679E-9*Tfilm(J)^4
1530    N(J)=N(J)*1.E-6
1540    !
1550    ! CALCULATION OF THE COEFFICIENT OF THERMAL
1551    ! EXPANSION [BETA]
1560    Beta(J)=.00246/(1.825-.00246*Tfilm(J))
1570    !
1580    ! CALCULATION OF ALPHA
1590    Alfa(J)=K(J)/(Rho(J)*Cp(J))
1600    !
1610    ! CALCULATION OF PRANDTL NUMBER.
1620    Pr(J)=N(J)/Alfa(J)
1630    !
1640    ! CALCULATION OF NUSSELT NUMBERS
1650    Nu1(J)=H(J)*L1/K(J)
1551    Nu2(J)=H(J)*L2/K(J)
1670    !
1710    ! CALCULATION OF GRASHOF NUMBER.
1720    Gr(J)=9.81*Beta(J)*(L1^3)*Delt(J)/N(J)^2
1740    !
1750    ! CALCULATION OF RAYLEIGH NUMBER.
1760    Ra(J)=Gr(J)*Pr(J)*1.E-7
1780    !
1794    ! CALCULATION OF FLUX BASED RAYLEIGH NUMBER
1810    Rai(J)=((9.81*Beta(J)*L1^4*Qnet(J))/(K(J)*N(J)*Alfa(J)*Atot))*1.E-9
1830    !
1870    !*********************************
1880    PRINT USING "10X,D.1X,5(5X,DD.DD,)":J,Qnet(J),Delt(J),Nu1(J),Nu2(J)
1890    !
1930    PRINT USING "12X,""FLUX BASED RAYLEIGH NUMBER * E-9 IS: "".DDD.DD":Rai(J)
1940    PRINT USING "12X,""AVERAGE TEMPERATURE:"".DDD.DDD":Tavg(J)
1950    PRINT USING "12X,""SINK TEMPERATURE:"".DDD.DDD":Tsink
```

118

```
1960  NEXT J
1970  ASSIGN #File TO *
1980  END
```

119

```
1       !+++++++++++++++++++++
10      ! PROGRAM FASTSCAN  +
11      !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
30      !PROGRAM TO SCAN THE THREE UPPERMOST THERMOCOUPLES.
40      ! IT SCANS 3 CHANNELS FOR TEMPERATURE VARIATION MEASUREMENTS.
41      ! CHANNELS ARE 13,31 AND 49
50      !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
60      Ipass=599
70      Pass=0
71      N=0
80      DIM T1(599),V1(2),Y1(599)
81      DIM T2(599),V2(2),Y2(599)
82      DIM T3(599),V3(2),Y3(599)
90      CLEAR 709
100     CLEAR 722
101     !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
102     ! THE THREE FILE NAMES THAT ARE REQUIRED FOLLOWING
103     ! ARE TO STORE THE READINGS FROM THREE THERMOCOUPLES.
104     !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
106     BEEP
107     PRINTER IS 701
108     BEEP
109     INPUT "ENTER THE FIRST FILE NAME: ",Newfile1$
110     INPUT "ENTER THE SECOND FILE NAME: ",Newfile2$
111     INPUT "ENTER THE THIRD FILE NAME: ",Newfile3$
112     INPUT "ENTER THE VOLTMETER READING: ",V$
113     PRINT USING "15X,""  RESULTS ARE STORED ON DISK 'FASTSCAN' "",10A"
114     PRINT
116     PRINT USING "25X,""FILE: "",10A":Newfile1$
117     PRINT
118     PRINT USING "25X,""FILE: "",10A":Newfile2$
119     PRINT
120     PRINT USING "25X,""FILE: "",10A":Newfile3$
121     PRINT
123     WAIT 1
124     BEEP
125     OUTPUT 709;"AE!"
130     WAIT 2
131     BEEP
140     OUTPUT 722;"T4 F1 R1 P0 Z0 1ST1 S01 1STN"
141     !
143     !++++++++++++++++++++++
144     ! LOOP NUMBER ONE  +
145     !+++++++++++++++++++++++++++++++
146     ! START SCANNING CHANNEL # 13  +
147     !+++++++++++++++++++++++++++++++
150     OUTPUT 709;"AF13 AL13"
160     OUTPUT 709;"AS"
170     BEEP
175     Timedate1=TIMEDATE
180     FOR Jj=0 TO Ipass
200     OUTPUT 722;"T3"
210     ENTER 722;V1(*)
220     T1(Pass)=V1(1)
250     Pass=Pass+1
251     N=N+1
260     NEXT Jj
261     Timedate2=TIMEDATE
263     Output(2);Timedate2-Timedate1
```

120

```
264   Pass=0
266   !***********************
267   ! LOOP NUMBER TWO      *
269   !***********************
271   ! START SCANNING CHANNEL 31   *
272   !*******************************
273   !
275   OUTPUT 709;"AF31 AL31"
276   OUTPUT 709;"AS"
277   BEEP
278   BEEP
279   FOR J1=0 TO Ipass
280   OUTPUT 722;"T3"
281   ENTER 722;V2(*)
282   T2(Pass)=V2(1)
283   Pass=Pass+1
284   NEXT J1
285   OUTPUT 722;"AC31"
286   Pass=0
287   !
289   !***********************
290   ! LOOP NUMBER THREE    *
291   !***********************
292   ! START SCANNING CHANNEL 49 *
294   !*******************************
295   !
297   OUTPUT 709;"AF49 AL49"
298   OUTPUT 709;"AS"
299   BEEP
300   BEEP
301   BEEP
302   FOR J1=0 TO Ipass
303   OUTPUT 722;"T3"
304   ENTER 722;V3(*)
305   T3(Pass)=V3(1)
306   Pass=Pass+1
307   NEXT J1
308   !
309   ! END LOOPS
310   !
311   PRINT USING "15X,""THE TOTAL TIME ELAPSED  )SECONDS("",2X,(DDD.DD)";Total
time
312   PRINT
313   PRINT USING "15X,""THE TOTAL NUMBER OF SCANS : "",2X, DDDD.D,2X ";N
314   PRINT
315   PRINT USING "15X,""THE VOLTMETER READING :  "",10A,"";VS
316   PRINTER IS 1
317   BEEP
318   !***************************************
319   ! TRANSFER FIRST SCAN DATA     *
320   !***************************************
322   ! TRANSFERING THE SCAN DATA FROM CHANNEL 13
323   ! TO THE FILE. THIS FILE WILL BE USED , WITH
324   ! THE PROGRAM "PLOT", TO MAKE A PLOT OF TEM-
325   ! PERATURE VS TIME.
326   !***************************************
328   CREATE BDAT Newfile15,20
329   ASSIGN #File TO Newfile15
330   OUTPUT #File;T1(*)
331   FOR I1=0 TO Ipass
332   T1(I1)=.10086091+25727.9*T1(I1)-757345.8*T1(I1)^2+78002556*T1(I1)^3
```

121

```
340    NEXT I₁
341    !+++++++++++++++++++++++++++++
342    ! TRANSFER SECOND SCAN DATA      *
344    !+++++++++++++++++++++++++++++++++
345    !TRANSFERING DATA FROM CHANNEL 31*
346    !TO THE FILE                      *
347    !+++++++++++++++++++++++++++++++++
349    CREATE BDAT Newfile2$.20
350    ASSIGN @File TO Newfile2$
351    OUTPUT @File:T2(*)
352    FOR I₁=0 TO Ipass
353    T2(I₁)=.10086091+25727.9*T2(I₁)-767345.8*T2(I₁)^2+78002556*T2(I₁)^3 ,
354    NEXT I₁
355    !
357    !+++++++++++++++++++++++++++++++++
358    ! TRANSFER THIRD SCAN DATA      *
359    !+++++++++++++++++++++++++++++++++++
360    ! TRANSFERING DATA FROM CHANNEL 31 *
361    ! TO THE FILE.                     *
362    !+++++++++++++++++++++++++++++++++++
363    !
364    CREATE BDAT Newfile3$.20
365    ASSIGN @File TO Newfile3$
366    OUTPUT @File:T3(*)
367    FOR I₁=0 TO Ipass
368    T3(I₁)=.10086091+25727.9*T3(I₁)-767345.8*T3(I₁)^2+78002556*T3(I₁)^3
369    NEXT I₁
390    STOP
400    END
```

122

```
10    !  FILE NAME: PLOT
20    !
40    !
50    ! THIS PROGRAM PLOTS THE DATA ACQUIRED BY
60    ! PROGRAM "FASTSCAN".
70    !
80      PRINTER IS 705
90      BEEP
100     Xmin=0
110     Xmax=200
120     BEEP
130     INPUT "ENTER MINIMUM AND MAXIMUM Y-VALUES",Ymin,Ymax
140     BEEP
150     Xstep=20
160     BEEP
170     Ystep=.2
180     BEEP
190     PRINT "IN;SP1;IP 2000,2000,8000,7000;"
200     PRINT "SC 0,100,0,100;TL 2,0;"
210     Sfx=100/(Xmax-Xmin)
220     Sfy=100/(Ymax-Ymin)
230     PRINT "PU 0,0 PD"
240     FOR Xa=Xmin TO Xmax STEP Xstep
250     X=(Xa-Xmin)*Sfx
260     PRINT "PA",X,".0; XT;"
270     NEXT Xa
280     PRINT "PA 100,0;PU;"
290     PRINT "PU PA 0,0 PD"
300     FOR Ya=Ymin TO Ymax STEP Ystep
310     Y=(Ya-Ymin)*Sfy
320     PRINT "PA 0,";Y,"YT"
330     NEXT Ya
340     PRINT "PA 0,100 TL 0 2"
350     FOR Xa=Xmin TO Xmax STEP Xstep
360     X=(Xa-Xmin)*Sfx
370     PRINT "PA";X,".100; XT"
380     NEXT Xa
390     PRINT "PA 100,100 PU PA 100,0 PD"
400     FOR Ya=Ymin TO Ymax STEP Ystep
410     Y=(Ya-Ymin)*Sfy
420     PRINT "PD PA 100,";Y,"YT"
430     NEXT Ya
440     PRINT "PA 100,100 PU"
450     PRINT "PA 0,-2 SR 1.5,2"
460     FOR Xa=Xmin TO Xmax STEP Xstep
470     X=(Xa-Xmin)*Sfx
480     PRINT "PA";X,".0;"
490     PRINT "CP -2,-1;LB";Xa;""
500     NEXT Xa
510     PRINT "PU PA 0,0"
520     FOR Ya=Ymin TO Ymax STEP Ystep
530     IF ABS(Ya)<1.E-5 THEN Ya=0
540     Y=(Ya-Ymin)*Sfy
550     PRINT "PA 0,";Y,""
560     PRINT "CP -5,-.25;LB";Ya;""
570     NEXT Ya
580     BEEP
590     Id1=0
600     IF Id1=0 THEN
```

123

```
520   Xlabel$="Time (sec)"
530   BEEP
640   Ylabel$="Temperature (C)"
550   PRINT "SR 1.5.2:PU PA 50,-10 CP";-LEN(Xlabel$)/2;"0:LB":Xlabel$;""
660   PRINT "PA -11,50 CP 0,";-LEN(Ylabel$)/2*5/6;"DI 0,1:LB":Ylabel$;""
670   END IF
680   PRINT "CP 0,0"
690   BEEP
700   INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
710   ASSIGN #File TO D_file$
720   BEEP
730   Md=0
740   BEEP
750   Npairs=600
760   BEEP
770   PRINTER IS 1
780   Sym=1
790   PPRINTER IS 705
800   PRINT "PU DI"
810   IF Sym=1 THEN PRINT "SM."
820   IF Sym=2 THEN PRINT "SM+"
830   IF Sym=3 THEN PRINT "SMo"
840   IF Md>1 THEN
850   FOR I=1 TO (Md-1)
860   ENTER #File:Xa,Ya
870   NEXT I
880   END IF
890   FOR Xa=0 TO 199 STEP .3333333
900   ENTER #File:Ya
910   Ya=.10086091+25727.3*Ya-767345.3*Ya^2+78002556*Ya^3
920   X=(Xa-Xmin)*Sfx
930   Y=(Ya-Ymin)*Sfy
940   IF Sym>3 THEN PRINT "SM"
950   IF Sym<4 THEN PRINT "SR 1.4.2.4"
960   PRINT "PA",X,Y,"PD"
970   IF Sym>3 THEN PRINT "SR 1.2.1.6"
980   IF Sym=4 THEN PRINT "UC2.4,99.0,-8.-4,0.0,9.4,0.:"
990   IF Sym=5 THEN PRINT "UC3.0,39.-3.-6.-3.6,3.6.3.-6:"
1000  IF Sym=6 THEN PRINT "UC0.5,3.99.3,-8.-5.0,3.9:"
1010  IF Sym=7 THEN PRINT "UC0.-5,3.99.-3.8,6.0.-3.-9:"
1020  NEXT Xa
1021  PRINT "PU"
1030  BEEP
1040  ASSIGN #File TO *
1050  END
```

124

LIST OF REFERENCES

1. Chu, R., "Heat Transfer in Electronic Systems," *Proc. of the Eighth International Heat Transfer Conference,* San Francisco, California, pp. 293-305, 1986.

2. Baker, E., "Liquid Cooling of Microelectronic Devices by Free and Forced Convection," *Microelectronics and Reliability,* vol. 11, pp. 213-222, April 1973.

3. Baker, E., "Liquid Immersion Cooling of Small Electronic Devices," *Microelectronics and Reliability,* vol. 12, pp. 163-173, 1973.

4. Park, K. A., and Bergles, A. E., "Natural Convection Heat Transfer Characteristics of Simulated Microelectronic Chips," *Transactions of the ASME, Journal of Heat Transfer,* vol. 109, pp. 90-96, February 1987.

5. Chen, I., Keyhani, M., and Pitts, D. R., "An Experimental Study of Natural Convection Heat Transfer in a Rectangular Enclosure with Protruding Heaters," paper presented at the National Heat Transfer Conference, Houston, Texas, 1988.

6. Keyhani, M., Prasad, V., and Cox, R., "An Experimental Study of Natural Convection in a Vertical Cavity with Discrete Heat Sources," ASME Paper No. 87-HT-76, 1987.

7. Kelleher, M., Knock, R. H., and Yang, K. T., "Laminar Natural Convection in a Rectangular Enclosure Due to a Heated Protrusion on One Vertical Wall— Part I: Experimental Investigation," *Proc. 2nd ASME/JSME Thermal Engineering Joint Conference,* Honolulu, Hawaii, pp. 169-177, 1987.

8. Lee, J. J., Liu, K. V., Yang, K. T., and Kelleher, M.D., "Laminar Natural Convection in a Rectangular Enclosure Due to a Heated Protrusion on One Vertical Wall— Part II: Numerical Simulations," *Proc. 2nd ASME/JSME Thermal Engineering Joint Conference,* Honolulu, Hawaii, pp. 179-185, 1987.

9. Liu, K. V., Kelleher, M. D., and Yang, K. T., "Three Dimensional Natural Convection Cooling of an Array of Heated Protrusions in an Enclosure Filled with a Dielectric Fluid," *Proc. Int. Symposium on*

125

Cooling Technology for Electronic Equipment, Honolulu, Hawaii, pp. 486–497; 1987.

10. Joshi, Y., Kelleher, M. D., and Benedict, T. J., "Natural Convection Immersion Cooling of an Array of Simulated Electronic Components in an Enclosure Filled with Dielectric Fluid," *Proc. of the International Symposium on Heat Transfer in Electronic and Microelectronic Equipment*, Dubrovnik, Yugoslavia, 1988.

11. Liu, K. V., Yang, K. T., Wu, Y. W., and Kelleher, M. D., "Local Oscillatory Surface Temperature Responses in Immersion Cooling of a Chip Array by Natural Convection in an Enclosure," *Proc. of the Symposium on Heat and Mass Transfer in Honor of B. T. Chao*, Univ. of Illinois, Urbana-Champaign, pp. 309–330, October 1987.

12. Pamuk, T., *Natural Convection Immersion Cooling of an Array of Simulated Chips in an Enclosure Filled with Dielectric Fluid*, Master's Thesis, Naval Postgraduate School, Monterey, California, December 1987.

13. Benedict, T., *An Advanced Study of Natural Convection Immersion Cooling of a 3 by 3 Array of Simulated Components in an Enclosure Filled with Dielectric Liquid*, Master's Thesis, Naval Postgraduate School, Monterey, California, June 1988.

14. Kreith, F., and Bohn, Marks, *Principles of Heat Transfer*, 4th ed., Table 11, p. 647.

INITIAL DISTRIBUTION LIST

127

9. Mr. Joseph Cipriano   1
    Executive Director
    Weapons and Combat Systems Directorate
    Naval Sea Systems Command
    Washington, DC 20362-5101

10. Naval Engineering Curricular Officer, Code 34   1
    Department of Mechanical Engineering
    Naval Postgraduate School
    Monterey, CA 93943-5004

11. LT Edgardo I. Torres   1
    Apartado Aereo 2845
    Cartagena Colombia